Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Advisory Committee on Radiological Protection

Guide to Ionizing Radiation Exposures for the Occupational Physician

INFO-0717

Prepared by the former Atomic Energy Control Board's Group of Medical Advisors as GMA-12.

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Canada

On May 31, 2000, the Atomic Energy Control Board became the Canadian Nuclear Safety Commission. In this document, references to the Atomic Energy Control Board or to the AECB should be read — unless the context requires otherwise — as references to the Canadian Nuclear Safety commission (CNSC). It should be noted that the Group of Medical Advisors no longer exists: its activities are now carried out for the Canadian Nuclear Safety Commission through the Advisory Committee on Radiological Protection.

The Canadian Nuclear Safety Commission (CNSC), and its predecessor the Atomic Energy Control Board, has made use of advisory committees of independent experts to assist it in its decision making process. The Commission has two senior level scientific committees charged with providing independent advice on principles, standards and general practices related to radiation protection and the safety of nuclear facilities. The two committees are the Advisory Committee on Nuclear Safety (ACNS) and the Advisory Committee on Radiation Protection (ACNS).

The Canadian Nuclear Safety Commission publishes many of the reports of its advisory committees. Publication by the CNSC does not imply endorsement of the content, nor acceptance of any recommendations made therein.

For information on the independent advisory committees contact: Advisory Committees of the Canadian Nuclear Safety Commission, Secretariat, Ottawa, Ontario K1P 5SP.

GUIDE TO IONIZING RADIATION EXPOSURES FOR THE OCCUPATIONAL PHYSICIAN: HOME PAGE

For viewers who are accustomed to a table of contents, please scroll down to the section entitled, "What does this document contain?". It is recommended, however, that you take a moment to read the introductory paragraphs in order to understand how this document is organized.

What is this document about and who is it for?

The purpose of this document is to organize the wealth of information available on the relationship of radiation and radionuclides to health outcomes, specifically for the occupational physician. Our priority in doing this has been to present this information in a way which will be useful to occupational physicians, rather than to present all the information that would be available for inclusion. Recognizing that occupational physicians are often faced with the task of presenting complex notions of risk to a "mass market" audience, we have deliberately avoided the tone of a scientific journal, offering instead additional reference material that the reader can use directly.

In a work environment where radiation exposure can occur, the occupational physician is often involved in the communication of information related to radiation exposures. An individual employee might be referred for consultation because of a specific radiation health question. A group of employees or managers might bring a collective concern to the occupational physician and ask for a group presentation in response. Or, the physician might be called on to give risk estimations at a judicial proceeding.

Few occupational physicians are in a position to assume responsibility for the care of even minor occupational injuries. It would be unlikely for a Canadian occupational physician to be primarily responsible for the care of an individual being treated for radioactive contamination or the effects of radiation exposure. However, the medical community may look to occupational physicians who are familiar with the radiation environment to provide advice on the management of radiation injuries.

Both of these functions of the occupational physician are closely tied with the estimate of radiation dose received by the worker. Radiation dosimetry is a specialist function and should not be attempted by the occupational physician. Information provided in this document is intended to sensitize the physician to the magnitude of radiation doses and illustrate how doses can be estimated - it is not intended to teach the physician to perform radiation dosimetry. The occupational physician should seek assistance from a health physicist for the dose estimate or for advice on other radiation related issues.

Occupational physicians are often requested to talk about chemical hazards for which few data from humans are available and for which quantification of risk may not be possible. It is important to note that this is quite often *not* the case with radiation hazards: there *is* a lot of information available that can lead to a dose estimate and a quantification of risk. Because of this, a much more measured approach to risk communication is necessary.

How is this document is organized?

This document provides information on the types of workplaces where radiation exposure of workers may be encountered. The focus of the document is on workplace situations (case studies) which face the occupational physician and on the steps which need to be taken to manage them. Relevant background material is provided so that the reader will be able to follow the development of each case study. The approach used in the development of the case studies will follow general principles of risk communication. Sources of additional information are also provided for those requiring more details. References, for example, are in hypertext so that the complete reference information can be easily found.

The workplace situations are divided into two broad classes:

a) Exposure-related presentations: situations where an actual or potential exposure to radiation has occurred, but a specific health effect has not yet been confirmed;

b) Health effects-related presentations: situations where a specific health effect has been confirmed, and a relationship to either known or suspected radiation exposure is proposed.

Each of these classes is divided further in order to help the user of this document locate information that is likely to be helpful in a particular case.

How do I use this document?

A skeletal outline of this document is provided to help you navigate. Numerous linkages are provided throughout the text to permit easy movement to relevant sections within this document. The Adobe Acrobat Reader default directional buttons will permit you to move forward, return to the first page, or go to the last page. Linkages are also provided to other relevant websites.

This document has been converted to Adobe Acrobat (.pdf) format and can be downloaded to your hard drive. To download, go back to your netscape browser, right click on the link to this document and use the "save link as" command. You can change the name of the file, but keep the file extension (.pdf) intact.

What information does this document contain?

HOW SHOULD I RESPOND TO QUESTIONS OR CONCERNS ABOUT RADIATION AND OCCUPATIONAL HEALTH?
- -General approach to risk communication

WHAT PROBLEMS ARE COMMONLY ENCOUNTERED IN THE WORKPLACE? (CASE STUDIES)
- -Occupational exposure to radiation
  - -external irradiation
  - -whole body and local irradiation
  - -contamination
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- -Factors which influence occupational exposure to radiation
- -Exposure related presentations
  - -external irradiation acute (1)
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  - -external irradiation: cosmic radiation
- -Health related presentation
  - -cancer
  - -reproduction (1)
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  - -skin
  - -eye
  - -other

WHERE CAN I GET MORE INFORMATION
- -on radiation, radioactivity, and radionuclides
  - -basic concepts
  - -radiation types
    - -alpha
    - -beta
    - -gamma
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-dose units
-biological effects
-acute radiation syndrome
-local radiation exposures
-risk estimates
-on workplaces where radionuclides may be encountered
-where radionuclides are encountered in the workplace
-fuel cycle
-Industry
-teaching and research
-medicine
-natural sources of radiation
-typical activities of commonly used industrial radionuclides
-description of commonly used radionuclides by source

-on specific radionuclides

-on local national and international sources of information

-on available technical resources
-human monitoring and bioassay capabilities
-dicentric chromosome analysis
-procedures for collecting blood for chromosomal analysis
-DTPA and Prussian blue
-procedure for obtaining DTPA and Prussian blue

-on places to get training

-on further reading and software

-on other useful websites

-on treatment of internal contamination
-reduction of gastrointestinal absorption
-blocking and diluting agents
-mobilizing agents
-chelating agents
-lung lavage
-hemodialysis
-treatment summary of selected internal radioactive contaminants

-on other documents by the Group of Medical Advisers
- GMA-6 Guidelines for Counselling after Occupational Overexposure to Ionizing Radiation
- GMA-8 Revised Guidelines for Medical Surveillance of Radiation Workers

WHAT ARE COMMONLY ASKED QUESTIONS
WHAT REFERENCES WERE USED TO CREATE THIS DOCUMENT
GLOSSARY OF TERMS
ACKNOWLEDGEMENTS

HOW SHOULD I RESPOND TO QUESTIONS OR CONCERNS ABOUT RADIATION AND OCCUPATIONAL HEALTH?

General Approach to Individual Risk Communication

Figure 1. Responding to a Questions/Concerns about Radiation and Occupational Health provides an outline of the general approach to responding to enquiries about radiation and occupational health. Listen first, then speak. Don't provide too much information initially because you think it's what the person should want to know, or because it's what you would want to know. Make sure you clearly understand the concerns.

It's often helpful in the first encounter, after offering to answer questions, to ask those you are dealing with to imagine all possible answers, e.g: Radiation did or did not cause my cancer. "I'll certainly do my best to help you figure that out. But perhaps I could help you even more if I understood what it would mean to you if we were able to determine that one way or the other."

Try to resist the temptation to correct any and all misunderstandings that you notice in the first meeting. Instead, try to rephrase them as questions, and state your commitment to research and report the answers. It is sometimes better to do this even if you know the answers off the top of your head.

At the end of the first meeting, it may be useful to confirm orally what you understand to be the individual's concerns. You may also want to follow this up in writing with a letter to the worker. Don't send the letter if it will take longer than a couple of days to reach the worker. The letter must be carefully worded, since it may influence the worker's expectations of what is to happen at the follow-up meeting.

Figure 2. Preparing a Final Response to a Question on Radiation and Health provides an outline of the steps which should be taken when preparing the final response to a question on radiation and health. Pay particular attention to apparent contradictions in what you are saying: for example, how can it be that the Workers' Compensation Board is compensating me for this illness, but the company doesn't appear to be accepting blame for having inadequate radiation protection practices? How can you say I have internal contamination yet I don't need to worry about playing with my children?

It is impossible to overstate the importance of the ability to explain the relationships between radiation sources and health outcomes in a way that is meaningful to the audience at hand. Some tools that can be used to assist you are provided in the section entitled "What questions are commonly asked". However, you will need to determine in each case whether or not they are appropriate for your use.

Figure 1. Responding to Questions or Concerns about Radiation and Occupational Health

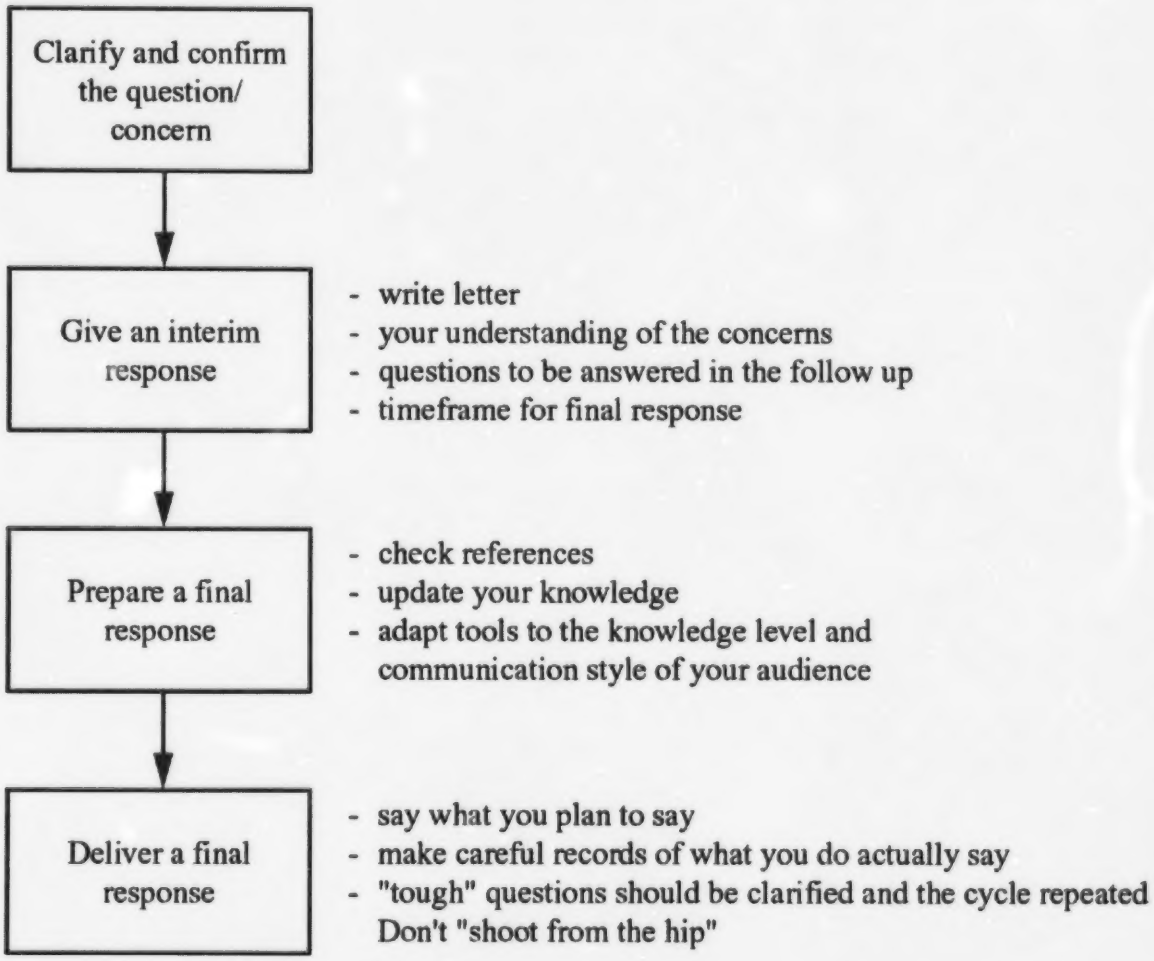
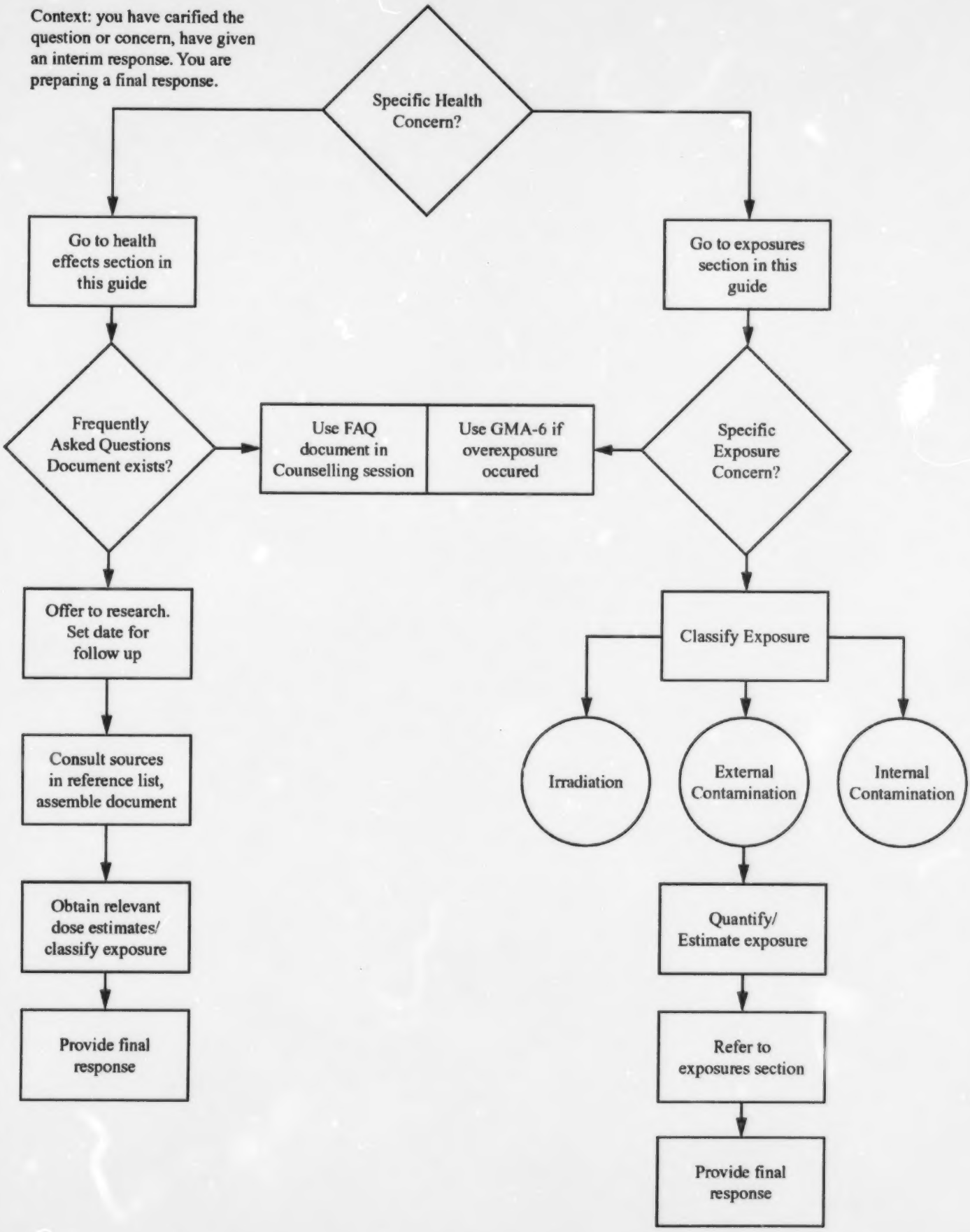

Clarify and confirm the question/ concern
Give an interim response
- write letter
- your understanding of the concerns
- questions to be answered in the follow up
- timeframe for final response
Prepare a final response
- check references
- update your knowledge
- adapt tools to the knowledge level and communication style of your audience
Deliver a final response
- say what you plan to say
- make careful records of what you do actually say
- "tough" questions should be clarified and the cycle repeated Don't "shoot from the hip"

Figure 2. Preparing a Final Response to a Question on Radiation and Health


Context: you have carified the question or concern, have given an interim response. You are preparing a final response.
Specific Health Concern?
Go to health effects section in this guide
Go to exposures section in this guide
Frequently Asked Questions Document exists?
Use FAQ document in Counselling session
Use GMA-6 if overexposure occured
Specific Exposure Concern?
Offer to research. Set date for follow up
Classify Exposure
Consult sources in reference list, assemble document
Irradiation
External Contamination
Internal Contamination
Obtain relevant dose estimates/ classify exposure
Quantify/ Estimate exposure
Provide final response
Refer to exposures section
Provide final response

WHAT PROBLEMS ARE COMMONLY ENCOUNTERED IN THE WORKPLACE?

Occupational Exposure to radiation

Factors which influence occupational radiation exposure

Exposure Related Presentations **(Case Studies)**

- External Irradiation - Acute Exposure (1)
- External Irradiation - Acute Exposure (2)
- External Irradiation - Chronic Exposure
- External Contamination - Acute Exposure
- Internal Contamination - Acute Exposure
- Internal Contamination - Chronic Exposure
- External Irradiation - Cosmic Radiation

Health Effects Related Presentations **(Case Studies)**

- Cancer
- Reproduction (1)
- Reproduction (2)
- Skin
- Eye
- Other

OCCUPATIONAL EXPOSURE TO RADIATION

Occupational exposure to radiation can occur as the result of external exposure (irradiation) from a source of radiation outside the body, or as the result of contamination.

External Irradiation

External radiation can originate from any number of sources such as an X-ray machine, an industrial radioactive source or a nuclear reactor. No direct contact between the radiation source and the person is involved. The individual is referred to as having been "externally exposed" or "externally irradiated". Once the person has been removed from the vicinity of the source, no further irradiation takes place. The person is not radioactive and those coming into contact with the irradiated person are in no danger of receiving any radiation exposure from this person.

Whole body and local irradiation

Depending on the workplace external radiation can involve the whole body or a part of the body only. In practice, the whole body is unlikely to be irradiated uniformly and in the case of a local exposure the irradiation results in a very steep gradient of absorbed dose from one portion of the body to another. Nevertheless, the distinction been whole body and local irradiation is helpful in understanding the effects of radiation.

Contamination

Contamination in this context refers to the deposition of radioactive material on skin or internal uptake via inhalation, ingestion, and entry through intact or broken skin. Even if a contaminated person is removed from the source of contamination, the person continues to be irradiated as long as radioactive materials are present on the surface of the body or internally. Contaminated persons may also pose a hazard to others by spreading contamination or by acting as a "radioactive source" themselves and irradiating others.

In order to reduce the exposure of the contaminated person and others, radioactive material must be removed from the surface of the body as soon as practicable, and measures must be taken to either prevent absorption of radioactive materials or enhance their excretion.

External Contamination

External contamination on a chronic basis should not occur in a workplace utilizing radiation protection practices. There should not be any external contamination outside of certain defined zones. Measures should be in place which will permit early notification of a contamination situation. Therefore, chronic exposure is unlikely. Should it occur, the source is removed and corrective action taken. Appropriate protection of workers will be required for remedial action, as well as dose rate monitoring and personal dosimetry.

Internal Contamination

While external contamination usually arises as a result of an accidental exposure, internal contamination may not be practically avoidable in certain occupations. Internal intake can result from the inhalation of radionuclides in air, ingestion or absorption through skin.

The duration of exposure will depend on both the physical half-life of the radionuclide and the persistence of the source in the body, or biological half-life. When an internal intake takes place the radionuclide will behave according to its chemical formulation. Some substances are readily absorbed, while others are not. Some are easily excreted, while others are retained in certain body tissues. Radionuclides that are in soluble form and chemically similar to essential nutrient elements will tend to follow pathways similar to their nutrient counterparts. For example, Strontium-89 and Radium-226 are similar to calcium and are bone-seeking elements. Cesium-137 follows the general pathway taken by potassium and is found throughout the body. Iodine-131 behaves like stable iodine and accumulates in the thyroid gland. Tritium is chemically equivalent to hydrogen and as tritiated water is found in body water. The radionuclide continues to decay, but is also being gradually eliminated from the body. The dose that is delivered to the body will therefore depend on the time after the intake has occurred.

The annual limit on intake of radionuclides is the amount of radionuclide taken into the body in one year that will result in a committed dose equal to the relevant annual dose limit. The International Commission on Radiological Protection publishes tables containing this information.

FACTORS WHICH INFLUENCE OCCUPATIONAL EXPOSURE TO RADIATION

There are several factors which influence occupational exposure to radiation. For external radiation exposure:

- time (dose increases with time, in the vicinity of the source),
- distance (the radiation received decreases with the square of increasing distance from the source),
- shielding (the protection afforded by a material between the source and the individual depends upon its composition and thickness),
- radioactive decay (the activity of the source decreases with time), and
- presence of contamination (and contact with the radioactive source).

For internal radiation exposure:

- time (exposure time increases dose),
- personal protective equipment (to reduce ingestion and absorption risk), and
- personal activities (refraining from eating, drinking and smoking in vicinity of source) and personal hygiene.

EXPOSURE RELATED PRESENTATION

CASE STUDY 1: External Irradiation - Acute Exposure

You are the occupational physician consulting for a small plant that makes polymer films and foils. During a recent plant shutdown for summer vacation, the thickness gauge used to control the manufacturing machinery was sent out for servicing. When it arrived at the service location, the technician noticed that the radiation source was not present. An investigation traced it back to the plant. It was found, still sealed, in a pile of old palettes on the loading dock. Very few people were in the plant except for the technician who removed the gauge, and the shipper/receiver.

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

Take the time to find out what the concerns of the potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE

Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified? No, at this point in time the concern is the potential exposure of some of the workers.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?

At this time it is uncertain whether or not anyone had been accidentally exposed. It will be important to determine whether the exposure (potentialabsorbed dose) is significant because this will determine the urgency and level of medical intervention. This information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion

Classify the exposure.
We know that the source was a sealed source which had been used in a thickness gauge. This means that the exposure will be limited to external irradiation of those near the source. There should be no external or internal contamination of workers.

Quantify/Estimate the exposure (this should be done with the assistance of a health physicist)
To estimate the dose to workers who were near the source, the following information will be needed:

(a) the **source**: What is the source? What is its activity?

Gauges often use gamma emitters such as cesium-137. Typical activities are in the 370 GBq range. Details on who to contact for this information, if not already known, should be available on the device label. Usually the manufacturer of the gauge or the Atomic Energy Control Board (AECB) will have this information. Information about the kind of radiation emitted from this source and its characteristics is provided in the section on specific radionuclides or can be obtained from reference document such as the Radionuclide and Radiation Protection Data Handbook.
Since an incident of this type is reportable to the AECB, it is likely that they would already be involved in the investigation.

(b) the **circumstances**: Who was exposed? How were they exposed (did they handle it, work near it, if so how close)? When and for how long were they exposed? Is there any sign of contamination? Were the workers wearing dosimeters?

This will require a detailed history and as much collaboration as possible. A site visit and a reconstruction of the scenario with a dose metre and the participants may be needed. The AECB may assist in the dose estimation.

While information is typically incomplete; it may be possible to estimate a worst case scenario upon which you can conservatively act.

Refer to sections on Radiation, radioactivity and radionuclides, Biological Effects, Acute Radiation Syndrome and Local Radiation Exposures
Is the estimated whole body dose high enough to have an immediate effect on health (1 Gy) or serious local injury (10 Gy)? Clinical signs which may assist are provided in the sections on Acute Radiation Syndrome and Local Radiation Exposures.
(It should be noted that radiation doses of this degree are unlikely to be encountered in Canadian workplaces, but for completeness this possibility will be developed further.)

If affirmative, urgent confirmation of your suspicions is needed and hospitalization should be considered. Confirmation of the radiation dose, and advice about the management of radiation injury can be sought from a health physicist at a nuclear power station or hospital, a nuclear medicine physician, a radiation oncologist or a university radiation safety officer. The acute management of local radiation injury is similar to managing thermal burns: preventing infection, controlling pain, initial immobilization and grafting.

If the victim needs hospitalization, you will need to reassure hospital administrators and clinical staff that the patient is not radioactive (presuming that there was no contamination). Baseline complete blood count (especially absolute count of lymphocytes) should be tracked and blood for cytology should be drawn in addition to normal baseline routine studies. Baseline ophthalmologic evaluation of the lens should be considered if exposure to the lens had occurred. Detailed information can be found in Diagnosis and Treatment of Radiation Injuries .

Apart from the assistance that might be available from the therapeutic radiation department of the referral hospital, advice on management of radiation injuries is available from:

- The Toronto Hospital (Toronto Western Division) Radiation Trauma Unit General (1-800-668-HELP).

- Radiation Emergency Assistance Centre and Training Site (REAC/TS) in the U.S.A.: (423) 576-3131. The 24 hour emergency number is 423-481-1000 (the switchboard of the Methodist Medical Centre in which REAC/TS is located)

- AECB Medical Liaison Officer (613) 995-1703 (days E.T.), (613) 995-0479 (duty officer after hours)

- Radiation Protection Bureau, Medical Adviser (613) 954-6647 (days E.T.)

If not hospitalized, the victim needs reassurance and some laboratory follow-up such as weekly blood counts for 5 weeks, as has been suggested by Andrews, to document the absence of significant injury. Cytogenetic analysis might also be considered to confirm the dose estimate or to reassure the victim.

GIVE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated. If an overexposure has occurred, guidance on counselling can be obtained in GMA-6 Guidelines for Counselling after Occupational Overexposure to Ionizing Radiation.

EXPOSURE RELATED PRESENTATION

CASE STUDY 2 : External Irradiation - Acute Exposure

Following completion of radiographic inspection activities at a small manufacturing facility, a 925 GBq Ir-192 sealed source fell out of its camera and remained unnoticed by those conducting the survey. The next day a female worker noticed the strange object and after examining it gave it to her co-worker who in turn took it to her supervisor who left it on her desk. Several hours later a representative of the radiography company contacted the supervisor to report the missing source and to advise that all employees be evacuated. Of the 76 employees intermittently in the vicinity of the course, 22 were females of child bearing age. The actual source in this instance was a 3 mm long cylinder contained in one end of 0.65 cm by 20 cm long stainless steel source holder. (This case study was based on a scenario used in the REAC/TS course March 1996).

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

Take the time to find out what the concerns of the potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE

Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

In cases of accidental exposure to radiation where the potential for early biological effects is high, the affected worker may become a part of the investigation which is needed to prepare the final response. The worker should be kept informed as much as possible throughout the investigation to allay any fears.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified? No specific health effect has been recognized however, it appears as though several workers have been exposed to the radioactive source.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?
Clearly there is a specific exposure concern in this case. From the history we know that at least two people physically handled the radioactive source and one may have worked in close proximity to it for several hours. Many others working in the vicinity of the source may have also been irradiated.

It will be important to determine whether the exposure (potential absorbed dose) is significant (whole body and /or local irradiation) because this will determine the urgency and level of medical intervention. This information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion. Given the large number of female workers concerns of a reproductive nature should be anticipated.

Classify the exposure.
We know that the source was a sealed source which had been used in radiography device. This means that the exposure will be limited to external irradiation of those near the source. Whole body irradiation and local irradiation, in those workers who handled the source, is expected.
External and internal contamination are not problems in this case because the source remains sealed.

Quantify/Estimate the exposure (this should be done with the assistance of a health physicist)
To estimate the dose to workers in the vicinity of the source or who handled the source, the following information will be needed:

(a) the **source**: What is the source? What is its activity?

We know that this is an Iridium-192 source containing 925 GBq of activity. Detailed information in this instance should be available from the radiographer. Information about the kind of radiation emitted from this source and its characteristics is provided in the section on specific radionuclides or can be obtained from reference documents such as the Radionuclide and Radiation Protection Data Handbook.

Since an incident of this type is reportable to the Atomic Energy Control Board (AECB), it is likely that they would already be involved in the investigation.

(b) the **circumstances**: Who was exposed? How were they exposed (did they handle it, work near it, if so how close)? When and for how long were they exposed? Is there any sign of contamination? Were the workers wearing dosimeters?

This will require a detailed history and as much collaboration as possible. A site visit and a reconstruction of the scenario with a dose metre and the participants may be needed. The AECB may assist in the dose estimation.

While information is typically incomplete; it may be possible to estimate a worst case scenario upon which you can conservatively act. This is particularly important in this case because of the close contact with the source.

NOTE: The steps in estimating the exposure from an external source are described below in order to demonstrate the principles involved. It is not recommended that occupational physicians perform such calculations. Rather, they should seek the advice of qualified experts in health physics. Both the Atomic Energy Control Board and the Radiation Protection Bureau of Health Canada have such expertise. Some hospitals also employ health physicists.

In this instance, we learn that the sealed source, Ir-192, is a gamma emitter. Gamma radiation is a penetrating form of radiation, travelling certain distances in air and penetrating human tissue. The

factors which must be considered in arriving at an estimate of dose are: activity of the source, energy of the radiation, quality of the radiation, distance from the source, and the length of time during which exposure occurred.

The activity of the source is assumed to be 925 GBq. However, once the actual activity of the source is identified it will be possible to determine the activity of the source at the time of the incident. This is done by extrapolating back in time using the physical half-life of the source. The amount of exposure now needs to be determined.

Scientific tables, organized by radionuclide, provide the amount of exposure from a unit of activity at a distance of one metre. Unfortunately many of the readily available tables use units of exposure which pre-date international units: the roentgen (R) is the unit of exposure in air, while the curie (Ci) is the activity of the source (1 Ci = 37 GBq).

For Ir-192 the exposure from one curie is 0.47 R/hr at 1 metre (from scientific table). Calculating exposure for a source of 925 GBq we obtain 925 GBq x 0.47 R/hr/Ci x 1 Ci/37 GBq at 1 metre, or 11.75 R/h at 1 metre.

For biological purposes the amount of exposure in air is not very useful and this must be converted to a unit of deposition of energy in tissue, or the absorbed dose, e.g., the gray (Gy). For low LET radiations, exposure of tissue to 1 roentgen (R) results in deposition of almost 1 rad (or, in international units, 10 mGy). This now equates to an absorbed dose rate of 117.5 mGy/hr at a distance of 1 metre.

As the radiation decreases with the square of the distance from the source it is also possible to estimate the dose rates at various distances, e.g., 1 cm (for finger tips, if the source was grasped at the "hot" end), 10 cm (for hand, if the source was grasped at "cold" end), 1 m (radiation to trunk for an estimate of whole body dose), 10 m, 100 m, etc. for (co-worker whole body exposure estimates).

From a reconstruction of the incident it is possible to estimate the local and whole body exposure (1 metre) and possible consequences for each employee.

For calculations involving the handling of radioactive sources time expressed in minutes may be more convenient. The dose rate, then, in Gy per minute at 1 metre would be 117.5 mGy/hr x 1 hr/60 min. or 1.96 mGy/min. At 10 cm and 1 cm the rates would be 1.96×10^{2} mGy/min and 1.96×10^{4} mGy/min, respectively. Conversely, the rates would be 1.96×10^{-2} mGy/min and 1.96×10^{-4} mGy/min for 10 and 100 m, respectively.

Calculation:

Note: Occupational physicians are advised to seek the assistance of qualified health physicists for the purposes of obtaining radiation dose estimates.

Exposure in air at one metre from a one curie Ir-192 source (from scientific table):

0.47 R/hr

Conversion of one curie to GBq:

1 Ci = 37 GBq

Exposure in air at one metre from a 925 GBq source:

925 GBq x 1 Ci/ 37 GBq x 0.47 R/ hr / Ci = 11.7 R/ hr

Conversion from exposure in air to absorbed dose for Ir-192 (from scientific table):

I R ≈ 1 rad

Conversion to international units (mGy are more convenient than Gy for occupational exposures):

1 rad = 10 mGy

Absorbed dose rate at one metre:

11.75 R/ hr x 10 mGy/ R = 117.5 mGy/ hr

Absorbed dose rate at one metre expressed in mGy per minute:

117.5 mGy/ hr x 1 hr / 60 min = 1.96 mGy / min

Using the inverse square law, the absorbed dose rate can be expressed at the following distances:

100 m	=	1.96×10^{-4} mGy / min
10 m	=	1.96×10^{-2} mGy / min
1 m	=	1.96 mGy / min
0.1 m	=	19.6 mGy / min
0.01m	=	196.0 mGy / min

Refer to sections on Radiation, radioactivity, and radionuclides, Biological Effects, Acute Radiation Syndrome and Local Radiation Exposures

Is the estimated whole body dose high enough to have an immediate effect on health (1 Gy) or serious local injury (10 Gy)? Clinical signs which may assist are provided in the sections on Acute Radiation Syndrome and Local Radiation Exposures.

(It should be noted that radiation doses of this degree are unlikely to be encountered in Canadian workplaces, but for completeness this possibility will be developed further.)

In the above case, serious local injuries are not expected because the time in direct contact with the source was probably in the order of minutes (this is why the history is critical). Whole body irradiation of biological significance might only be expected in the worker on whose desk the source remained. Only if the worker sat at one metre from the source continuously for an eight hour period could a dose close to 1 Gy could have been received.

If a significant dose was estimated, confirmation of your suspicions is needed and hospitalization should be considered. Confirmation of the radiation dose, and advice about the management of radiation injury can be sought from a health physicist at a nuclear power station or hospital, a nuclear medicine physician, a radiation oncologist or a university radiation safety officer. The acute management of local radiation injury is similar to managing thermal burns; preventing infection, controlling pain, initial immobilization and grafting.

If the victim needs hospitalization, you will need to reassure hospital administrators and clinical staff that the patient is not radioactive. Baseline complete blood count (especially absolute count of lymphocytes) should be tracked and blood for cytology should be drawn in addition to normal baseline routine studies. Baseline ophthalmologic evaluation of the lens might be considered if exposure to the lens had occurred. Detailed information can be found in Diagnosis and Treatment of Radiation Injuries .

Apart from the assistance that might be available from the therapeutic radiation department of the referral hospital, advice on management of radiation injuries, including where to secure available antidotes for internal contamination, is available from:

- The Toronto Hospital (Toronto Western Division) Radiation Trauma Unit General (1-800-668-HELP).

- Radiation Emergency Assistance Centre and Training Site (REAC/TS) in the U.S.A.: (423) 576-3131. The 24 hour emergency number is 423-481-1000 (the switchboard of the Methodist Medical Centre in which REAC/TS is located)

- AECB Medical Liaison Officer (613) 995-1703 (days E.T.), (613) 995-0479 (duty officer after hours)

- Radiation Protection Bureau, Medical Adviser (613) 954-6647 (days E.T.)

If not hospitalized, the victim needs reassurance and some laboratory follow-up such as weekly blood counts for 5 weeks, as has been suggested by Andrews, to document the absence of significant

injury. Cytogenetic analysis might also be considered to confirm the dose estimate or to reassure the victim.

GIVE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated. It may helpful to put the exposure into context by comparing it to the regulatory occupational dose limits. In this case, the dose limits are set by the Atomic Energy Control Board (Canadian Nuclear Safety Commission), the Canadian regulator of radioactive materials and nuclear facilities. The occupational dose limit is 100 mSv over 5 years with 50 mSv in any one year. The dose limits for pregnant workers are more restrictive in order to protect the fetus. The dose limits for pregnant workers proposed under the Canadian Nuclear Safety and Control Regulations are 4 mSv (this is roughly equivalent to about 2 mSv to the fetus). This differs slightly from what has been recommended by international organizations. Given the number of young women employed in this work site this is a good opportunity to remind women of their obligation to inform their employers when they become pregnant in order for their working conditions to be reviewed.

If an overexposure has occurred, guidance on counselling can be obtained in GMA-6 Guidelines for Counselling after Occupational Overexposure to Ionizing Radiation.

EXPOSURE RELATED PRESENTATION

CASE STUDY 3: External Irradiation - Chronic Exposure

A clerk from the administration section in the hospital approaches you. She says that her office is right below the nuclear medicine department, and she is concerned that she may be getting exposed. She wonders why she is not included in the dosimetry program. How do you respond to her concerns?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Before investigating it might be worth inquiring why this is a concern at this time. Has an incident occurred or someone she knows developed a cancer?

It is important to take the time to find out what the concerns of potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
No health effect was identified.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?
It will be important to have some idea of this worker's radiation exposure in order to answer her concern about being close to the nuclear medicine department and her question about being included in a dosimetry program. Addressing her concerns is essential in bringing the intervention to a successful conclusion.

Classify exposure

The worker is worried about the on-going (chronic) exposure she may have to radiation from the nuclear medicine department one floor above her office. The nuclear medicine department may employ sealed and unsealed sources of radiation. There are many routes of exposure in a nuclear medicine department but for the worker one floor below the only one of concern is external irradiation from gamma sources. She will not have any contact with radioactive materials or regular contact with patients who have been given radioactive materials and are themselves slightly radioactive. Therefore there is no potential for external or internal contamination.

Quantify or estimate exposure

To estimate the dose to workers who were near the source, the following information will be needed:

(a) the **source**:

A site visit to her workplace as well as the nuclear medicine department should put the situation in context and may yield other information such as the psychosocial factors as well as the physical environment. An interview with the Radiation Control Officer would be helpful in reviewing radiation control procedures, monitoring and dosimetry of the nuclear medicine department. The Radiation Control Officer could survey the office while the latter department is operating. Finally the construction and shielding of the nuclear medicine department should be reviewed.

(b) the **circumstances**:

Who else considers themselves potentially at risk and if so how long?

Refer to sections on Radiation, radioactivity, and radionuclides and Biological Effects

It should now be possible to determine the worse case risk for exposure. If it is minimal, reassure her. If she has a lingering concern, perhaps a dosimetry trial would reassure her. If there is cause for concern, ensure that the senior manager, Health and Safety Officer and the Health and Safety Committee are informed by the Radiation Control Officer. Counselling regarding long term risks from the exposure should be appropriate to the circumstances and level of anxiety.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated. It may be helpful to put the exposure into context by comparing it to the dose limits for members to the public. The use of radioactive materials in the nuclear medicine departments of hospitals is regulated by the Atomic Energy Control Board (Canadian Nuclear Safety Commission) and a yearly dose limit for members of the public such activity is set at 1 mSv.

EXPOSURE RELATED PRESENTATION

CASE STUDY 4: External Contamination - Acute Exposure

You are the occupational health physician in a university laboratory. A scientist calls because she has just had an accident. She was stirring a solution in a fume hood that contained a radioisotope label. The solution in the flask, which should have been clear, suddenly turned brown and began to smoke. The flask then shattered, and she has some pieces of glass in her hand. The ambulance was called, but they would not take her, because they said she was radioactive. What should be done?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

It is important to take the time to find out what the concerns of potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears. Finally, the workers need to be confident that they are getting appropriate care and accurate information.

In this case there is a medical condition which needs attention. There is also the issue of the ambulance workers' concern about handling this person. Both of these situations may require immediate attention. The affected worker may have immediate concerns or fears, or may only present with these concerns later. It will be important to keep in touch with the worker during the treatment phase to allay any immediate concerns. Clarification of other concerns may have to wait until later.

GIVE INTERIM RESPONSE

First aid treatment can be administered at the work site. Partial decontamination at the work site may be possible if the wounds are not severe. The degree of precaution needed to limit the spread of contamination when the worker is transported to the hospital will depend on the characteristics of the radioisotope.

After the treatment, and once the concerns have been clarified repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?

Apart from the immediate injury, no health effect resulting from radiation was identified.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?
Radioactive material has spilled and come into contact with the skin and a wound.
It will be important to determine whether the exposure (potential absorbed dose) is significant because this will determine the urgency and level of medical intervention. This information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion.

Classify exposure
This is a case of external contamination of the skin, and possibly clothing, and internal contamination via a wound. Any radioactive material on the skin will continue to irradiate the individual until it is removed.

The aim of treatment is to reduce the radiation dose by decontaminating the affected tissues as rapidly as possible, and to reduce the scattering of the radioactive contaminant.

Skin and wound areas should be monitored for radiation contamination (a health physicist should be consulted if one is available). Before beginning decontamination, the injuries must be prioritized for decontamination. Since she has glass in her hand, the broken skin will be an entry point for internal contamination. The injured areas should be cleansed with saline solution, H_2O_2, or betadine. Pieces of glass which are easily accessible should be removed to permit irrigation of the wounds. Solution used for decontamination and the glass fragments which are removed should be saved in order to help identify the radionuclide and its activity (if not known).

Finally, surrounding healthy skin should be washed with cool water to reduce surface contamination and reduce spread. Soap and water, Phisoderm, H_2O_2 Chlorox, or a mixture of cornmeal and Tide may be appropriate.

More information on decontamination can be found in Assessment and Treatment of external and internal radionuclide contamination and Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers.

Quantify or estimate exposure (this should be done with the assistance of a health physicist)
To estimate the radiation dose to the skin or whole body information is needed on:

(a) the **source**: What is the source? What is its activity?
Generally radioactive substances which are used as labels have low activity and are beta emitters, with the exception of iodine-125, which emits gamma rays. Apart from the risk of contamination, the injured worker would pose little risk to health care workers. Information on handling casualties who are contaminated with radioactive materials can be found in Guidelines on Hospital Emergency Plans for the Management of Minor Radiation Accidents.

A health physicist should be consulted in order to estimate the radiation dose. There are tables provided in publications such as the Radionuclide and Radiation Protection Data Handbook which help to estimate the dose to the skin from contamination with unsealed sources.

The internal dose from intake via the wound may be more difficult to estimate and may require techniques such as bioassay of urine samples.

(b) the **circumstances**: How much of the skin was contaminated? For how long before decontamination was successful?

Refer to sections on Radiation, radioactivity, and radionuclides, and Biological Effects

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

EXPOSURE RELATED PRESENTATION

CASE STUDY 5: Internal Contamination - Acute Exposure

A valve bursts in a research reactor building releasing a small amount of mixed radioisotopes into the building atmosphere in the form of steam. Several people have contaminated clothing. Nasal swabs are strongly positive. Physicists are working on characterizing the isotope mixture present in the steam. What else should be happening? How would you follow up with this case?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

It is important to take the time to find out what the concerns of potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears. Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE

First aid treatment can be administered at the work site if needed. External decontamination at the work site is possible by removal of clothing and decontaminating the skin. Advice on external decontamination methods is provided in Guidebook for the treatment of accidental internal radionuclide contamination of workers. Positive nasal swabs suggest that an internal contamination has taken place by inhalation, but other routes are also possible. Treatment for internal contamination may be needed and should be dealt with before the other concerns.

After the treatment, and once the concerns have been clarified, repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
While contamination has taken place, no immediate health effect resulting from radiation was identified.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?
Surface contamination has taken place and there are signs of internal contamination also.
It will be important to determine whether the exposure (potential absorbed dose) is significant because this will determine the urgency and level of medical intervention. This information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion.

Classify exposure
Exposure to mixed radioisotopes is a potential health concern. In this case, a specific exposure is known to have occurred with mixed radioisotopes in the form of steam. This can result both in external contamination and internal contamination via inhalation.

Workers should be removed from the source of contamination as soon as possible and workers who are contaminated should immediately proceed with decontamination procedures (removal of clothing, showers, flushing eyes) to minimize the time of exposure on skin and mucosal surfaces. This will reduce the final dose. Any excreta (urine, feces, emesis) should also be saved until further notice. (Remedial action and accident investigation will be carried out with the appropriate precautions such as suits, respirators, etc.)

Radioisotopes within the body will continue to irradiate the body until they physically decay or are eliminated from the body.

Quantify or estimate exposure (This should be done with the assistance of a health physicist.)
To estimate the radiation dose received by the workers information is needed on:

(a) the **source**: What are the mixed radioisotopes? What are the activities?

Identification of mixed radioisotopes will be made by physicists at the nuclear generating station. The CANDU reactor used in Canada differs from other reactor designs in the quantity and the type of fission products it produces. There are many radionuclides that fall into the category of fission products. Their decay pathways are diverse and their metabolic pathways in the body differ.

An estimation of the intake and subsequent estimate of dose in this case is extremely complex. Health physicists use bioassay procedures to estimate internal contamination by the measurement of radioactivity in excreta (urine, feces, emesis) , other biological samples, or by direct *in-vivo* measurement.

In-vivo measurements are preferred wherever possible because they measure what is in the body. However, they are costly, and are not always possible if the radionuclide emission is not sufficiently penetrating . Radionuclides emitting high energy photons should be measured by *in-vivo* analysis using a whole body counter. Radionuclides which decay solely with emission of low energy beta particles cannot be measured in this way unless there are accompanying photon emissions with characteristic energies which can be used to identify the radionuclide.

When alternative methods such as urinalysis are used (for radionuclides which are excreted), intakes must be estimated from the measurement of what is excreted, using complex models. Annual limits on intake (ALI) for radionuclides have been published by the International Commission on Radiological Protection. The ALI is the intake in any year of a radionuclide which will result in a committed effective dose to Reference Man of 20 mSv.

An estimate of the dose from the intake can be made using tables for committed dose per unit intake published by the International Commission on Radiological Protection (ICRP) in publications 30, 61, and 67-68. The dose coefficients are derived primarily from human data as well as from studies in laboratory animals using standard biokinetic methods and human reference models.

Information on resources for whole body counting and bioassay is provided in the section on Human Monitoring and Bioassay capabilities.

(b) the **circumstances**: Were therapeutic measures used to decrease the dose to the affected workers?

As a general guideline, if the estimated committed organ dose exceeds 2.5 Sv or a committed effective dose is greater than 250 mSv, therapeutic measures should be considered. If a significant intake of radioiodine is suspected prophylactic potassium iodide pills should be taken as quickly as possible to block the uptake of radioiodine by the thyroid gland. Other therapeutic measures are discussed in the section on Treatment of internal contamination with radionuclides. It should be noted that not all drugs recommended for this use are approved in Canada. Obtaining drug approval in order to stockpile such drugs for emergency use can take considerable time.

Estimates of the committed organ dose or committed effective dose are modified as more information becomes available during the treatment (ie. new bioassay results).

Refer to sections on Radiation, radioactivity, and radionuclides, Biological Effects
Internal contamination can be severe enough to cause acute effects, but this is not likely in the above scenario. For more information see sections on Biological effects, and Acute Radiation Syndrome.

PROVIDE FINAL RESPONSE
With a dose estimate and an understanding of the individual's concerns a final response can be formulated. If an overexposure has occurred, guidance on counselling can be obtained in GMA-6 Guidelines for Counselling after Occupational Overexposure to Ionizing Radiation.

EXPOSURE RELATED PRESENTATION

CASE STUDY 6: Internal Contamination - Chronic Exposure

Recently a hygienist decides to test the basement of your office building for radon. It turns out that the levels are high. Several people work down in the basement all day long. What do you tell them?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

It is important to take the time to find out what the concerns of potentially affected workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears. Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE

Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?

No specific health effect has been identified.

Go to Exposures related presentations in the Case Studies section of this guide.
(You are in this section now)

Is there a specific exposure concern?

The workers have been breathing air with high concentrations of radon gas. This is not really a case of internal contamination since radon gas is ubiquitous, but it is internal irradiation of the lung that is the issue.

It will be important to determine whether the exposure is significant because this will determine the need for intervention. This information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion.

Classify exposure

It has been determined that exposure to indoor radon may be above a designated limit. In workplaces which are not uranium mines, or buildings under federal jurisdiction, occupational exposures to radon are the responsibility of the provincial occupational health authorities. For federal employees, radon exposure is limited to 800 Bq/m^3 (Canada Gazette Part II, Vol. 130, No.13 the Canadian Occupational Safety and Health Regulation, Section 10.26 (4) states that *" No employee, other than an atomic radiation worker, as defined in the Atomic Energy Control Regulations, shall be exposed in the course of any year to a concentration of radon that on average, over the year, is higher than 800*

Bq/m³.") The International Commission on Radiological Protection has suggested that 500-1500 Bq/m³ be an action level for workplaces.

Quantify or estimate exposure

The hygienist will have used a short-term radon test which is useful as a screening tool. To get an assessment of personal exposure, however, an extended measurement period of one year is recommended due to significant seasonal variation [CM97].

After the appropriate testing is complete the need for remedial action can be determined. Individual exposures can be assessed using a conversion factor [IC93]. Established risk coefficients can then be used to estimate the risk of cancer from continued exposure at the measured level.

Refer to sections on Radiation, radioactivity, and radionuclides, and Biological Effects

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

General information about radon will have to be given to the workers and depending on the occupational safety and health policy they may have to be removed from the basement until a more accurate picture of the exposure is established [CM97].

EXPOSURE RELATED PRESENTATION

CASE STUDY 7 : External irradiation: Cosmic radiation

You are an occupational physician for an airline. There has been a news story indicating that aircrew can receive higher radiation doses than some radiation workers. You are contacted by a few pilots and flight attendants about getting radiation monitors to see how much radiation they are receiving.

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN

It is important to take the time to find out what the concerns of potentially affects workers are. Their concerns may be more related to the increased risk of cancer and negative reproductive outcomes than to the immediate consequences of the exposure. Even workers with considerable experience may have unexpected concerns or fears. Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE

Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

If you already have written material available on cosmic radiation, this could be provided now. Details about the individual exposure and risks will be part of the final response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?

No specific health effect has been identified.

Go to Exposures related presentations in the Case Studies section of this guide.

(You are in this section now)

Is there a specific exposure concern?

Aircrew and passengers are exposed to more cosmic radiation at air carrier altitudes than at sea level. It is possible for the annual occupational radiation exposure of aircrew to exceed that of some workers in radiation-related occupations.

Cosmic radiation consists of mainly charged particles (ie., mostly protons and alpha particles) travelling through space. As these particles interact with the earth's atmosphere they produce secondary particles of a different composition. As these particles descend towards the earth's surface they are attenuated (ie., scattered and absorbed) in the atmosphere which acts as a shielding material. Altitude is therefore an important factor in determining the radiation dose. For example, the radiation dose rate at 40,000 feet (12 km) is about 40% of that at 70,000 feet (21km).

The earth's magnetic field also influences the radiation received since it can deflect the incoming charged particles, making the flight latitude an important factor. For a altitude, the radiation dose rate over the poles is about twice that over the equator. In practice, this means that a north Atlantic flight

between Canada and Europe will encounter more cosmic radiation than a flight at the same altitude between Canada and Mexico.

The earth's magnetic field is affected by the activity of the sun which has approximately an 11 year cycle. During periods of low solar activity the sun's magnetic field is lower and therefore less effective in deflecting galactic cosmic rays from entering into our solar system, resulting in a greater cosmic radiation dose.

Occasionally solar flares are produced which give rise to high doses for short periods of time. Solar flares cannot be predicted with any great accuracy although they fluctuate with solar activity. Only at very high altitudes, typical of supersonic transport (SST) Concorde travel, ie. 49,000 - 59,000 feet (15-18 km), could this contribute significantly to dose.

The following are examples of doses which could be received from cosmic radiation on some typical Canadian-based air carrier flights:

Grouped global flight region	Sample Route	Scheduled flight time	Route dose (μ Sv)
Trans-Pacific	Peking-Vancouver	10h 40min	44 (+/- 10)
Trans-Atlantic	Vancouver-London	9h 06min	39 (+/- 16)
Trans-Canada	Toronto-Vancouver	4h 26min	21 (+/- 6)
Caribbean	Cancun to Toronto	3h 37min	21 (+/- 4)
Northern Canada	Ottawa to Iqaluit	2h 50min	11 (+/- 4)

The need for intervention will be determined by the aircrew exposure. Such information is equally important for addressing the specific concerns of those involved; this is essential in bringing the intervention to a successful conclusion.

Classify exposure

There are no specific regulations in Canada pertaining to cosmic radiation exposure. International radiation protection associations such as the International Commission on Radiological Protection (ICRP) have suggested that occupational exposure to cosmic radiation during jet aircraft flights be treated as other occupational radiation exposures. ICRP recommends an occupational dose limit of 20 mSv per year (averaged over 5 years). This is occupational dose limit is expected to be adopted for nuclear energy workers in Canada under the new Canadian Nuclear Safety and Control Act (which is expected to come into force late 1999). The present occupational dose limit in Canada is 50 mSv. Similarly, the public dose limits for exposures arising from activities licensed by the Canadian Nuclear Safety Commission (now the Atomic Energy Control Board) are expected to fall from 5 mSv to 1 mSv per year.

The ICRP also recommends that the radiation exposure of pregnant women be further limited to protect the conceptus. The additional equivalent radiation dose to the conceptus should be limited to about 1 mSv for the remainder of the pregnancy.

Quantify or estimate exposure

There is considerable information in the scientific literature concerning cosmic radiation exposure during jet aircraft flight. Recently the Royal Military College of Canada conducted an extensive survey of the radiation environment aboard several Canadian air carriers on domestic and international flights. This work has resulted in the development of a database of route doses and an algorithm to estimate an individual's cosmic radiation dose based on flight history. During the study, a sample of aircrew measured their individual radiation exposures for up to a year using personal dosimeters. The results indicate that most Canadian based domestic and international aircrew will exceed and effective dose of 1 mSv per year, but will remain below 5 mSv per year. While this is well below the occupational dose limits specified elsewhere, it does exceed that recommended for pregnant workers. To help put the exposure into perspective it might be useful to point out that living in Canada we receive just over 2 mSv per year from natural background radiation. The cosmic radiation component of that, at sea level, is about 0.3 mSv.

Even without obtaining an individual dose assessment the above information should be sufficient to explain the risks from cosmic radiation exposure. More information on radiation risks can be found in the section entitled Risk Estimates. Cosmic radiation does differ in its composition from radiations encountered in most terrestrial occupations. However, when the dose is expressed as an effective dose, the different quality of this radiation has been taken into account and the risk estimates are still believed to be applicable. Some epidemiological studies of aircrew exposed to cosmic radiation have been conducted and others are in progress. So far, findings are inconsistent and difficult to interpret due to combined exposures.

Since some workers may request individual monitoring it is important to note that the dose received on board an air carrier will be much the same regardless of location on the carier. Individual monitoring of dose. Using personal dosimeters, is therefore not necessary to obtain a dose estimate. Knowledge of an individual's flight history and a route dose database are all that are needed. However, a database such as this will need to be validated periodically, if for no other reason than to taken into account changes in the solar cycle.

PROVIDE A FINAL RESPONSE

With an estimate of the yearly dose and an understanding of the individual's concerns a final response can be formulated. General information about cosmic radiation should be given to affected workers.

HEALTH RELATED PRESENTATION

CASE STUDY 1: Cancer

You receive a referral from a union. One of their members works in the radio pharmaceutical industry. He has recently been diagnosed with and treated for a testicular tumour. They want your opinion about the compensability of this condition. He is now feeling well, and wants to return to work. Is it still OK for him to be working with radiation? He says he had a lot of x-rays and other tests during the cancer treatment.

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the workers are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
Yes. The health concern in this case is cancer, specifically testicular cancer.

Refer to Health Related Presentations in Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

Cancer is the most important health effect of low level radiation. Two basic assumptions are made about radiation induced cancer: any dose, no matter how small, is believed to increase the risk of cancer, and, the risk increases with the dose. The increased risk of a fatal cancer from occupational radiation exposure has been estimated by the International Commission on Radiological Protection to be 4.0%/Sv when the radiation is evenly distributed throughout the body. The increased risk of total health detriment from all late effects of radiation is 5.6%/Sv (this figure includes all cancers and heritable effects).

While, there are some individuals with known increased sensitivity to radiation due to chromosomal defects (i.e., ataxia-telangiectasia), there is no way today to unequivocally prove or disprove a claim that a specific malignancy was caused by a specific radiation exposure. An approach has been developed to estimate the probability that an individual's malignancy was caused by radiation exposure, known as the probability of causation. This is an epidemiology-based method which takes into account age, sex, time since exposure, type of malignancy, and dose. The use of probability of causation (PC) estimates can be useful in adjudicating compensation claims from individuals who have been occupationally exposed to radiation. In many Canadian provinces a system of "presumptive favour" towards the workers is used, and no PC calculation is done. In such situations a disease is assumed to have been caused by the exposure if the worker can confirm the exposure and a medical certificate confirms the malignancy. In some provinces a minimum exposure is required before awarding compensation.

Generally, radiation induced cancer develops following a latent period. The minimum latency for leukaemia is about 2 years but averages about 8-10 years. For solid tumours, the minimum latency is 10 years, but often is more than twenty years. Since the peak incidence of testicular cancer is between ages 20-35, it is unlikely that occupational exposure of sufficient duration would have occurred to increase the risk.

Certain tumours appear to be more commonly caused by radiation than others. Leukaemia seems to be the first to emerge. Lung, breast and thyroid tumours seem to be readily induced by radiation. According to the epidemiologic literature testicular cancer does not appear to have a causal relationship with radiation exposure. There are, however, other factors known to predispose to the development of testicular cancer such as undescended testes, history of mumps orchitis, etc.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood of a radiogenic cancer.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

Concerning return to work, the worker may be advised that a history of treatment for cancer does not preclude him from radiation work, if he is otherwise fit for his job. The additional risk of radiation related disease is small in comparison with the risks from the original treatment with surgery, radiation or chemotherapy. Radiation doses administered as part of medical treatment are far greater than occupational exposures and can significantly contribute to the risk of developing a secondary cancer. If the worker wishes to return to work and is fit he can be permitted to do so. Some consideration may need to be given to the prognosis of the individual case. In the case of localized forms of germinal cell cancer the cure rate is high when treated with surgery or radiation and even advanced disease has the potential for cure.

HEALTH RELATED PRESENTATION

CASE STUDY 2: Reproduction

A couple comes to you at your office at a fuel refining and fabrication plant. Both of them work in the plant. They have been trying for a year to conceive, but have been unsuccessful. They are both in their 20's and are otherwise apparently healthy. Their GP suggested that they speak to you about the possibility that radiation was affecting their fertility.

They are also concerned that their work with radiation will increase the possibility that they will have a child that has either birth defects or childhood cancer of some sort. The woman has also been told that she should not breast feed, because the radiation might wind up in her milk. What do you say?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the workers are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
Yes. The immediate health concern is infertility.

Refer to Health Related Presentations in Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

Reproductive organs are sensitive to radiation. Single doses of as little as 0.1 Gy to the testes are reported to have made men temporarily sterile. The dose needed to result in permanent sterility from testicular irradiation varies considerably: reports suggest that a dose as small as 2 Gy is sufficient but most reports are in the range of 5-6 Gy. Changes in sperm count from an acute exposure appear in

about 30-60 days. The testes differ from other organs in that the same dose spread out over time tends to cause more, not less damage.

The ovary is rather less sensitive, at least in adult women. In adult women under 40 an acute dose of about 3-5 Gy to the ovary is needed to result in permanent sterility.

A secondary concern is that if a child is conceived it might be born with a genetic defect, a congenital anomaly, or it may develop cancer during childhood. The fetus is particularly sensitive to radiation and each of the above health effects are associated with radiation exposure.

Irradiation of the germ cells in reproductive organs has the potential to cause hereditary disease in offspring. Although an increased risk of genetic damage has not been observed in human populations exposed to radiation, it has been demonstrated in animals. The estimated risk of causing hereditary disease in all subsequent generations is 0.8%/Gy. The background incidence of hereditary defects is believed to be in the order of 10% of live births.

When a fetus is irradiated *in utero* there is a potential for the development of congenital malformation, depending on the dose to the fetus and the period of gestation. Before implantation, radiation exposure can also result in prenatal death (resorption). The most sensitive period of gestation for congenital malformation is the period of organogenesis. Small head size, growth retardation and mental retardation seem to be the only effects identified in association with radiation exposure. Small head size is most prevalent if exposure occurs during weeks 2-15 post conception. There appears to be a threshold for the above effects in the 100 mGy range. It is useful to note that the background incidence of congenital anomalies is about 6% of live births.

A lowering of IQ by 3- points per Sv has also been detected for exposures during 8-15 weeks and is somewhat less during the 16-25 week period when the brain continues to develop significantly.

Irradiation *in utero* also has the potential to cause childhood cancer (mainly leukemia). As in adults, it is the probability of developing a cancer that increases with the dose. Studies of *in utero* exposure have given a wide range of estimates, from high risk to none at all. It is assumed that the risk is higher than for adults. The background frequency of childhood cancer death is about 20/10,000 live births [Bo90]. The average age for radiation induced childhood cancers to appear is 3-5 years.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood that radiation is a cause of the particular health problem.

The dose histories of each of the workers will be useful for comparative purposes. Depending on the nature of their work, their exposures may involve external radiation as well as internal intakes of uranium. Radiation doses needed to damage reproductive organs are not normally encountered in occupational settings. Occupational exposure to other chemicals which might affect fertility should also be considered.

The reported doses will probably be in the form of "whole body dose" and "skin dose". "Uranium intake" may be reported separately. If the doses are within recommended limits no effect on fertility is expected. If there is a history of accidental overexposure, a calculation of the dose to the organ of interest will have to be made. There are computer programs available to do this (see section on Further reading and software), but the health physicist can assist in this determination.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

HEALTH EFFECTS PRESENTATION

CASE STUDY 3: Reproduction

A research lab graduate student who was working with tritium discovered she was pregnant. As she was concerned for the fetus she sought advice from her family physician who suggested that she have an abortion. She was uncertain about what to do and sought another opinion from the occupational physician.

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the worker are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

Discussion with the student revealed that the student was looking forward to having this baby and was not happy with the advice regarding an abortion. She was just concerned with the risks to the fetus from her occupational exposure.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
The specific concern relates to the health of the fetus.

Refer to Health Related Presentations in Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

There is considerable anecdotal evidence that women receive conflicting advice in these circumstances. Geneticists and teratologists generally suggest that in cases where a 50 mGy dose to the fetus is anticipated, counselling be done. This figure exceeds the occupational dose limit for pregnant workers and is likely to be far greater than her actual occupational exposure.

In utero effects are also discussed in the Health Related Case study #2.

Pre-conception exposure of the mother to ionizing radiation theoretically could give rise to infertility, chromosomal abnormality and genetically determined congenital malformation or cancer in her offspring. These effects arise the same way as mutations do and cannot be demonstrated in humans; one reason is that the spontaneous mutation rate exceeds the radiation induced mutation rate.

Post-conception exposures could give rise to heritable change (from germ cell mutation), childhood cancer (from somatic cell mutation), and teratogenic effects. While there is evidence of heritable change in animals this has not been shown in man. Evidence of heritable change in animals includes fetal loss, altered sex ratio, birth defects, cancer in offspring, infertility and subclinical DNA or protein changes. There is still some controversy surrounding the risk of childhood cancer from radiation exposure in utero. The evidence for an increased risk for childhood leukemia is the most substantial [Do97] and consistent with the risk coefficient of 0.06 per Gy. The absolute risk for childhood leukemia is small.

Finally, there appears to be a narrow window of time during gestation in which to produce teratogenic effects from radiation. In the first 8 days there is an "all or none" effect. Later, the embryo's ability to replace dead cells depends on the organ involved. Irradiation during the period of organogenesis (approximately days 18-40) could result in major malformation, while effects on the brain and the sex cells may continue throughout gestation.

What has actually been observed is an increased risk of small head size, seizure disorder and mental retardation. The greatest risk for small head size is in the first 7 weeks of gestation. It is not always associated with mental retardation. There is an increased risk for seizure disorder when exposure occurs during weeks 8-15. The risk for mental retardation is probably the most important risk, especially if exposure occurs during weeks 8-15, and somewhat less if exposure occurs during weeks 16-25. The risk per gray of severe mental retardation following in utero exposure is 43% compared to a 0.8% background. A threshold for this effect is believed to be in the range 60-300mGy.

The doses quoted above are uterine doses which are used as surrogates for the fetal dose.
Occupational doses are usually expressed as effective dose - in the case of pregnant workers, the fetal dose needs to be estimated.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood that radiation is a cause of the particular health problem.

This worker is exposed to tritium, a low energy beta emitter, which is important when there is internal intake. As tritiated water, tritium can be absorbed through intact skin. Inhalation as water vapour is more common. Most of the tritium is distributed in body water and turns over with a biological half-life of about 10 days. Some of the tritium is incorporated into organic compounds and this turns over with a longer half-life. It will cross the placenta. Exposure to organically bound tritium is associated with a longer biological half-life.

The worker's past exposure history or that of workers who conduct similar tasks can be used as a guide for what to expect over the course of the pregnancy - should alternative working arrangements not be practicable. Exposure to internal intakes of tritium is monitored using bioassay methods. Pregnant workers are generally monitored more frequently than non-pregnant workers because dose rate is important in the embryo and fetus. The limit on intake is the amount of radionuclide taken into the body in one year that will result in a committed dose equal to the relevant dose limit.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

Potential fetal effects can arise from pre-conception or post-conception exposure. However, the short answer to her concerns is that her occupational exposure will result in a risk to the fetus which is far smaller than the "background" risk.

HEALTH RELATED PRESENTATION

CASE STUDY 4: Skin

A radiation worker comes to you complaining of a mild burning sensation on his face. He also notices a small lump on the left cheek. You examine it and find an appearance compatible with a wart. Is there any cause for concern?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the worker are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
The immediate health concern is the burning sensation which the worker has experienced. If there was the potential for accidental overexposure to his face an accident investigation should be commenced so that a dose can be estimated.

Refer to the Health related presentations in the Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

Accidental contact with a sealed source or exposure to a beam of penetrating radiation could result in a serious injury. If an estimate is not possible, the timing of the clinical signs and symptoms can be used to estimate the skin dose. See the section on Local radiation exposures. The dose estimate helps the treating physician plan treatment. If the suspect area of skin is close to the eyes it may be prudent to have an ophthalmologic follow-up.

Complaints such as a superficial feeling of irritation, tenderness or itching can be precursors to radiation burns. Other causes of these symptoms, such as soap or detergent reaction, other skin

applications or sunburn should be ruled out. The course of radiation burns varies considerably. With large doses there may be initial erythema, edema, and blistering with ultimate tissue loss. With lower doses there may be no initial signs or complaints until a week later when erythema develops. This may progress to ulceration, fibrosis and tissue loss. Or, the erythema may resolve in 4-8 weeks with only residual hyper pigmentation.

Type I injury is erythema and does not progress. Type II injuries usually heal but skin is pigmented, thin and easily injured (D_{50} = 6 Gy) Type III injuries are associated with a gradual obliterating endarteritis with resulting fibrosis, atrophy and tissue death (dermal radio necrosis D_{50} = 20 Gy). Penetrating radiation may damage the structures of the subcutaneous tissue and cause a progression of symptoms over many months. At levels greater than 50 gray, blistering and skin loss can take place within a very short time after the accident depending on the energy of the radiation. In such cases, not only is the subcutaneous tissue damaged, but other internal structures (bone, muscle) may be affected as well. Hospitalization may be required for the treatment of radiation burns.

Late effects which may be expected are those resulting from progressive tissue atrophy, fibrosis, and chronic radiodermatitis.

Chronic low dose radiation exposure produces premature skin aging. Chronically irradiated skin should be managed as a pre-malignant condition and any keratoses and ulcerations excised. Squamous cell carcinoma occurs most frequently. Radiation induced skin cancer has not been observed in the absence of radiodermatitis.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood that radiation is a cause of the particular health problem.

In this case, if an accidental exposure to a fine beam had occurred to the face, the radiation would not have been detected by the dosimeter which is usually worn on the trunk. Consequently, the dose record may not be of assistance and a reconstruction of the accident and dose received may be needed.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

HEALTH RELATED PRESENTATION

CASE STUDY 5: Eye

A 60 year old nuclear medicine technician approaches you. She has been diagnosed with cataracts and needs an operation. She thinks that the time off work should be compensable by the Workers' Compensation Board because of the type of work she does. What do you say?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the worker are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
A cataract has been identified.

Refer to the Health related presentations in the Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

The lens of the eye is sensitive to radiation. Acute or chronic radiation exposure of the lens of the eye can lead to cataract development. Unlike most other cataracts, the initial lesion in a radiation induced cataract begins in the posterior subcapsular part of the lens. Ultimately the opacity progresses to the anterior lens cortex, at which time it is indistinguishable from a cataract due to other causes. There appears to be a threshold for the development of cataracts. Following an acute dose of about 2 Gy to the lens, it may take a latent period of about 12 years before a cataract becomes manifest. The higher the dose the greater the loss of vision. Serious progressive cataracts occur after 5 Gy. Chronic exposure of 0.5-2 Gy over 10-20 years increase the density and opacity of the lens.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood that radiation is a cause of the particular health problem.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated.

It is unlikely for a nuclear medicine technician to have a significant exposure to the lens of the eye.

HEALTH RELATED PRESENTATION

CASE STUDY 6: Generalized symptoms

A 45 year old man working in a nuclear power plant comes to you. He has noticed recently that his hair is thinning, he is having trouble controlling his weight, and he is losing interest in sex. He feels generally tired. He thinks it must be because of the radiation, and he wants a medical transfer to a different type of job, perhaps in the office. What do you tell him?

The text will follow the algorithm provided in Figure 1 & Figure 2.

CLARIFY AND CONFIRM THE QUESTION/CONCERN
Take the time to find out what the concerns of the worker are. Even workers with considerable experience working with radionuclides may have unexpected concerns and fears.

Finally, the workers need to be confident that they are getting appropriate care and accurate information.

GIVE INTERIM RESPONSE
Repeat your understanding of the concerns and questions which need to be answered in the follow up. Give a time frame for response.

PREPARE A FINAL RESPONSE

Has a specific health effect been identified?
Very general symptoms have been identified by the worker. Such complaints may be associated with a wide range of medical conditions, including depression.

Refer to the Health related presentations in the Case Studies section of this guide.
(You are in this section now)

Do documents already exist with relevant communication tools?
Check the sections on Commonly asked questions. These can be used in counselling sessions.

Conduct research
See section on Where can I get more information.

If the man's dose history confirms that he has had low level radiation exposure he will have to be presented with information to explain that his symptoms are not directly related to radiation (unless he has a radiation induced cancer). Hair loss can occur with high doses of radiation to the skin in the 3-10 Gy range. Similarly, fatigue is associated with significant acute radiation exposures.

Obtain relevant dose estimates and classify exposure

Both the employer and the National Dose Registry keep radiation dose records of workers. An individual may request a copy of his dose record from the National Dose Registry (613) 954-6660. An estimate of the dose and its probable distribution in the body can provide some idea of the likelihood that radiation is a cause of the particular health problem.

PROVIDE FINAL RESPONSE

With a dose estimate and an understanding of the individual's concerns a final response can be formulated. This man should be advised to see his physician for a general assessment if he continues to feel unwell.

WHERE CAN I GET MORE INFORMATION

...on radiation, radioactivity and radionuclides

...on workplaces where radionuclides may be encountered

...on specific radionuclides

...on local, national and international sources of information

...on available technical resources

...on places to get training

...on further reading and software

... on other useful websites

... on treatment of internal contamination with radionuclides

...on other documents by the Group of Medical Advisers

RADIONUCLIDES, RADIOACTIVITY AND RADIATION

Basic Concepts
Radiation types:

- Alpha Particles
- Beta particles
- Gamma rays (photons)
- X-rays
- Neutrons

Dose Units
Biological Effects
Acute Radiation Syndrome
Local radiation injuries
Risk estimates

BASIC CONCEPTS

An atom is the smallest part of an element that will exhibit the chemical and physical properties of the element. Most species of atom can be characterized by the name of the element and the mass number. Thus characterized, they are called nuclides. The fundamental components of atoms are protons, neutrons, and electrons. It is the number of protons that determine the chemical properties of the element.

The term **isotope** refers to any two or more species of atoms making up an element with the same atomic number (same number of protons), but with different atomic mass (because of different number of neutrons).Isotopes will exhibit the same chemical properties.

Most of the atom's mass consists of the neutrons and positively charged protons which form a tiny nucleus. The negatively charged electrons, which balance the charge of the protons, orbit around the nucleus in a diameter which is about 100,000 times larger than the nucleus. This concept of the atom as mostly empty space is important in understanding radiation interactions.

Some nuclides are stable but many are not. The stability of a nucleus is determined by the numbers of protons and neutrons, their configuration, and the forces they exert on each other. These unstable nuclides, or **radionuclides**, spontaneously tend to rearrange themselves into a more stable configuration by emitting subatomic energetic particles or high-energy photons (gamma rays, electromagnetic waves). The original atom is called the parent and the transformed one, a nuclide of a lighter element, is called the **daughter, decay product or progeny**. The process of emitting energetic particles or waves is called **radioactivity**. The process of transformation is called **radioactive decay**.

When a radionuclide undergoes several transformations before becoming a stable nuclide, the path it follows is known as a **decay chain or sequence**. Each unique transformation, or **disintegration**, is associated with a discrete amount of energy emitted. Because of the spontaneous nature of transformations, a radionuclide can follow more than one path. Its decay can therefore be associated with the emission of more than one type of particle and more than one energy. The energy associated with the radioactive decay of a specific radionuclide can be expressed in terms of **minimum, maximum and average energy.** This information is clinically important because the type of particle and its energy will determine how far the radiation will travel in air and how far it can penetrate tissues.

All radionuclides decay at a unique rate, depending on how unstable they are. The strength, or **activity**, of a radioactive source is a measure of its rate of decay. This rate can also be expressed in terms of the amount of time for the activity of a quantity of radionuclide to lose half its value by decay, or **physical half-life**.

Radiation refers to the process in which energy is emitted by one body or source, transmitted through an intervening medium or space, and absorbed by another body. If the energy transferred to an atom in the absorbing material is high enough, an electron may be ejected from the atom, thereby producing an ion pair, in a process known as **ionization**. The amount of energy present is measured in electron

volts. Examples of ionizing radiation are x-rays, gamma rays, alpha particles, beta particles and neutrons.

If the medium is a living cell, this can result in biological damage from the disruption of chemical bonds. For example, ionization may directly damage the DNA by causing single or double strand breaks. Or, it may cause damage indirectly by producing highly reactive oxygen and hydroxyl atoms (free radicals) in the cell water, which in turn can disrupt the DNA.

RADIATION TYPES

Alpha Particles

Alpha particles are large positively charged, relatively slow moving particles (Helium nuclei) which are ejected from the heavy nuclei of radionuclides such as uranium-238. There are several naturally occurring radionuclides which emit alpha particles. Typically their energy is in the 4-8 MeV(mega electron volts) range. They produce a dense track of ionizations as they pass through materials. This is important because errors in cellular repair are more likely to occur when sites of damage are close to each other (e.g., double strand breaks in DNA). However, due to their large mass they do not have penetrating power and can be stopped by a sheet of paper or by the superficial layer of dead cells of the skin. Their range in air is a few centimetres and in tissue about 50 μ m. Thus, alpha radiation is only a hazard when substances emitting it get into the body (internal contamination). This may occur by inhalation, ingestion or absorption through wounds in the skin.

Beta particles

Beta particles are small charged particles (electrons), relatively faster moving and producing less ionizations compared with alpha particles. They are ejected from the nuclei of many radionuclides, such as tritium (even though there are no electrons, as such, in the nucleus, a neutron can transform into a proton and an electron). The typical energy range is 0-3 MeV. They travel up to several metres in air but usually penetrate only a few millimetres into skin, and can be stopped with plastic gloves. The depth of their penetration in skin depends on their energy (as much as a centimetre or more for highly energetic beta), which is a characteristic of the radionuclide from which they were emitted. Beta radiation can be hazardous to superficial tissues such as the skin or the lens of the eye from external radiation or external contamination. It is hazardous to internal tissues only when radionuclides which emit beta particles are ingested or inhaled (internal contamination).

Gamma rays (photons)

Gamma rays, or photons, are bundles of energy with no mass or charge. Gamma rays often accompany the emission of alpha or beta particles from a nucleus. They belong to the electromagnetic spectrum and travel at the speed of light. The typical energy range is from 0-3 MeV. Although they produce less ionizations than alpha or beta particles, they are more penetrating. Lead, concrete, or water can provide shielding. Gamma rays travel many metres in air and many centimetres in tissue, being able to pass through the body. Gamma radiation is therefore hazardous both as external radiation and internal contamination. Their origin gives rise to specific discrete energies which are characteristic of a specific radionuclide and can be identified with a gamma ray spectrometer.

X-rays

X-rays are also discrete quantities of electromagnetic energy, without mass or charge. However, x-rays originate from processes occurring outside the nucleus of the atom. X-rays are generally lower in energy than gamma rays and therefore somewhat less penetrating. X-rays can be made by bombarding a metal target in a vacuum with a stream of high energy electrons which in turn react with

electrons orbiting the nucleus. The resultant energy of the photons varies directly with the applied voltage.

Neutrons

Neutrons are rarely abundant except from man-made sources such as nuclear reactors. They are emitted from the nucleus during fissioning from neutron sources such as Americium/Beryllium,or as a result of particle acceleration. Since they are quickly absorbed by the nuclei of surrounding atoms, they are found only near sources that can create nuclear reactins, and only while they are in operation. Neutrons are heavy particles (atomic mass of 1) with no charge and a typical energy range of 0-5 MeV. They produce a fairly dense track of ionizations, but less so than alpha. Their range in air is many metres and penetration in tissue, several centimetres. Due to their source, neutrons are only an external radiation hazard. When certain materials are irradiated by neutrons, they can become radioactive - this does not occur with other types of radiation.

A single energetic particle or photon may interact with tissue several times causing many ionizations before it loses its excess energy. When ionizing radiation passes through a medium, it leaves a trail of electrical charge in its wake. Its path is called the track. The longer the track length in tissue, the greater the degree of penetration. The amount of energy lost per length of track is referred to as the **linear energy transfer (LET)**. The penetrating power of ionizing radiation is related to the mass and charge of the particle as well as the kinetic energy. The more mass and electrical charge a particle possesses, the more ionizations per unit length of path (higher LET) and the quicker the particle stops (penetrates less).

Alpha particles are comparatively large and can scarcely penetrate the outer protective layer of skin, hence radionuclides that emit alpha particles pose little hazard unless they are taken in the body. Beta particles are smaller and can penetrate a centimetre or so in tissue, consequently they pose an external hazard to superficial tissues as well as being an internal hazard. Gamma rays, x-rays and neutrons penetrate deeply and hence pose a hazard even at a distance from the source.

DOSE UNITS

As already indicated, activity or radioactivity is a measure of how much radioactive material is present in a sample; it is the number of atoms undergoing radioactive decay per second. One disintegration per second is designated as one **becquerel (Bq)**. This is an international unit. The conventional unit is a curie (Ci) and the conversion factor is 1 Ci = 3.7×10^{-10} Bq.

Exposure refers to the measurement of a radiation level to which a person may be exposed. The principle unit is the **roentgen (R)**. It describes an amount of ionization per unit mass in air (which differs from denser tissues). This term is not easily converted to dose and is not often used.

There is a special unit for inhalation exposure to radon progeny in air, the **working level month**. It is equivalent to a 170 hour exposure to 1 working level, which is the concentration of radon progeny in equilibrium with 3700 Bq per cubic metre of radon gas.

When ionizing radiation passes through living tissue, some of the energy is deposited in the material as a result of electrical interactions (ionizations). This electrical charge results in chemical changes in cells which can lead to biological damage. The measure of energy transfer from the radiation to the tissue is the **absorbed dose**. It is defined as the amount of energy deposited by the radiation in the tissues and organs of the body. The unit used to express absorbed dose is the **gray (Gy)**; one gray corresponds to one joule per kilogram. An older unit to express absorbed dose is still in common use - the rad (1 Gy = 100 rad).

One type of radiation may be more damaging than another. The same absorbed dose of alpha radiation, for example, is twenty times more damaging than gamma radiation because of its dense path of electrical charge (Table 1). To put all ionizing radiations on an equal basis with regard to their potential for causing harm, the absorbed dose is multiplied by a weighting factor to give an **equivalent dose**. The unit used to express the equivalent dose is the **sievert (Sv)**; it also corresponds to one joule per kilogram. The equivalent dose provides an index of harm from exposure to any kind of radiation. 1 Sv of alpha radiation to the lung causes the same harm as 1 Sv of gamma radiation to the lung. The sievert is actually a very large unit and in practice millisieverts mSv are used. An older unit for equivalent dose which is still in common use is the rem (1 Sv = 100 rem).

Table 1: Radiation Weighting Factors[1] Recommended by the International Commission on Radiological Protection [IC91]

Type and energy range	Radiation weight factor
Photons, all energies	1
Electrons	1
Neutrons, energy < 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

[1] All values relate to the radiation incident on the body or, for internal sources, emitted from the source.

The magnitude and type of damage produced by radiation varies from one body tissue to another. For example, 1 Sv to the lung would cause a different type and degree of harm than 1 Sv to the thyroid. To equalize the harmful effects of the same equivalent dose, tissue weighting factors are assigned to different body parts (Table 2). These factors take into account probability of developing cancer, its prognosis, years of life expectancy lost and probability of developing a genetic defect.

Table 2: Tissue Weighting Factors Recommended by the International Commission on Radiological Protection [IC91]

Tissue or Organ	Tissue or Organ
Gonad	0.20
Bone Marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05*

* Includes adrenals, brain, upper large intestine, small intestine, kidney, muscle, spleen, thymus and uterus

When equivalent doses in all tissues are multiplied by the tissue weighting factors and summed, the result is the **effective dose.** The unit of effective dose is also called the sievert. Thus, the same amount of harm results from an effective dose of 1 Sv of alpha radiation to the lung as does 1 Sv of uniform whole body irradiation with gamma rays. This concept is useful when trying to determine the total amount of harm which results from different radiation exposures.

Unless otherwise specified the term "dose" in this document is the "effective dose".

Another important dose unit is the **committed effective dose**. Radionuclides taken into the body by inhalation, ingestion, or absorption through the skin may remain in certain tissues and organs for extended periods of time. Therefore the resulting dose to the internal organs may be delivered over several days or years. The committed effective dose is the total dose received from a radioactive substance in the body during the remainder of an individual's life, taken to be 50 years for an adult. The committed dose from internal sources is included in any calculation of effective dose.

Therefore, the effective dose is a broad indicator of risk to human health from any type of radiation and any distribution of dose in the body, whether received internally or externally.

BIOLOGICAL EFFECTS

High doses of radiation delivered at high dose rates (acute exposure) can result in a variety of early effects such as cell death, organ dysfunction and death (Table 3). Examples of such effects are radiation burns and acute radiation syndrome which is characterized by nausea, fatigue, vomiting, blood cell loss, diarrhoea, temporary sterility, and possible death. These effects, called **deterministic effects** are associated with a threshold dose below which no effect is seen. The severity of these effects is related to the amount of radiation received [UN88].

Most organs can repair damage from radiation to some extent and tolerate a series of smaller doses better than the same total dose given at once. Conditions such as radiodermatitis, posterior pole cataracts, infertility (decline in sperm count may take years to recover once exposure ceases), and thyroid dysfunction, usually only occur as a result of a significant acute dose. For the same effects to occur from chronic exposure, the exposure would have to be considerably higher. The exception in this case is the testes. Exposures of this magnitude do not normally occur in today's workplaces, however. Sometimes late effects such as cataracts and chronic skin damage occur, but such effects are rare.

Radiation at low doses and low dose rates (less than 200 mSv and less than 0.5 mSv per minute), as may be experienced in the occupational setting, is more likely to produce **stochastic** effects rather than "deterministic" effects. These effects are probabilistic or random - it is the likelihood of experiencing the effect that is related to the amount of radiation received. Examples of such effects are cancer and genetic damage. When cells are exposed to low levels of radiation biologically important molecules, such as DNA, can be injured directly, or indirectly via the production of free radicals in the cytoplasm. If cellular damage is not adequately repaired, it may result in a modified cell that is capable of producing a cancer after a prolonged and variable period of time. Damage to sperm or egg cells may result in effects which are expressed in the offspring. There is no clear threshold for these effects and it is assumed that there is a risk for developing a stochastic effect from radiation from any dose, no matter how small.

Unfortunately there is nothing to distinguish these effects as arising from radiation as opposed to other causes. Furthermore, in attributing delayed effects to radiation, uncertainties in exposure measures, long latency period, and confounding factors such as smoking, other carcinogen exposure, hereditary effects, etc., must be considered.

Some organs are more likely than others to result in cancer from radiation. These are the bone marrow (except chronic lymphocytic leukemia), thyroid, breast, lung and bone [Me90].

Table 3: Selected Examples of Mammalian Radiobiologic Damage [Vo94]

Level of Damage	Important Effects
Molecular	Damages macromolecules, including DNA, RNA, and enzymes; interferes with metabolic pathways
Subcellular	Damages cell membranes, mitochondria, lysomes, nuclei, and chromosomes
Cellular	Inhibits cell division, kills cells; causes carcinogenesis
Organ	Injures bone marrow, intestinal tract, cardiovascular and central nervous systems, with minor changes to acute deaths in severe exposures
Whole Body	Death, cancer
Populations	Gene and chromosomal mutations in individuals can change characteristics of offspring

These biologic effects are affected by a number of factors [Vo94]:

dose rate	the body's biological repair processes have a greater likelihood of success if a given dose of radiation is delivered over a longer time period (lower dose rate).
dose fractionation	similarly, division of a total dose into smaller fractions given over separate times causes less biologic damage than the same total dose given at one time
tissue sensitivity	tissues made up of rapidly dividing cells are markedly more sensitive to radiation than are tissues composed of slowly dividing cells (e.g., germinal, bone marrow and intestinal epithelial cells)
age	similarly, the fetus is more highly susceptible than young children who in turn are more susceptible than adults
dose distribution	a person can survive larger doses to limited parts of the body (that preserves some bone marrow) than to a uniform dose to the entire body
individual variation	this can be of the order of two or more times a specific dose
chemical factors	the presence of certain chemical factors at the time of radiation can enhance or reduce the biologic effect. Known sensitizers include oxygen and halogenated pyrimidimes and protective agents include a variety of sulphur-containing compounds.

Table 4: Examples of Temporary Effects [UN88, Me90]

Temporary Effect	**Threshold** (acute 24-48 hr. exposures)
sterility in men	above 0.1 Gy; duration dependent on dose
vomiting or retching with feeling of mild to moderate fatigue	about 0.3 Gy; 50% incidence at about 2 Gy; severity increases with dose
decrease in lymphocyte count and other white blood cells	0.5-1.0 Gy for measurable effects; severe effects above 2 Gy
erythema of the eye conjunctiva	about 2 Gy
erythema of the skin with changes in vascular permeability	about 3 Gy for exposure to entire skin; about 6 Gy for small areas of skin
hair loss	3-5 Gy

Table 5: Examples of Permanent Effects [UN88, Me90]

Permanent effect	**Threshold** (acute 24-48 hr. exposures)
eye cataracts	minimum stationary cataracts at 1-2 Gy; more serious progressive cataracts above 5 Gy
permanent sterility in men	above 5 Gy, single dose
permanent sterility in women	above 3 Gy
bone marrow damage	about 3-5 Gy; 50% killed in one to two months
damage to blood vessels	above 5 Gy
impairment of lung function, pneumonitis	above 5 Gy
impairment of thyroid, liver and kidney function	above 10 Gy
gastrointestinal death	above 5 Gy; kills in about one to two weeks
skin desquamation with possible scarring	above 10 Gy
central nervous system death	above 50 Gy; kills within 72 hours

ACUTE RADIATION SYNDROME

Exposure of the entire body to a large radiation dose, over 1 Gy (100 rad) in a single exposure, or within 1 or 2 days, results in a progressive series of signs and symptoms known as the **acute radiation syndrome**. A patient's survival is threatened at doses of 2 Gy or more, with the estimated LD_{50} being about 3.5 Gray after 60 days of receiving a homogenous whole body dose; the LD_{50} increases to about 4 or 5 Gy with corrective treatment at a specialized hospital.The syndrome develops in a characteristic time pattern after short-term, high dose, penetrating external ionization radiation exposure. Depending on the magnitude of the exposure, the hematopoietic system, the gastrointestinal tract, cardiovascular and central nervous systems may be involved in damage in an ascending order of severity. Table 6 summarizes the principal clinical effects in relationship to acute whole body doses of various magnitudes.

Table 6 : Dose-Effect Relationships Following Acute Whole-Body Irradiation (X-ray or gamma) [Vo94]

Whole-Body Dose (Gy)	Clinical or Laboratory Findings
0.05-0.25	Asymptomatic. Conventional blood studies are normal. Chromosome aberrations detectable
0.50-0.75	Asymptomatic. Minor depressions of white cells and platelets detectable in a few persons, especially if baseline values established
0.75-1.25	Minimal acute doses that produce prodromal symptoms (anorexia, nausea, vomiting, fatigue) in about 10% to 20% of persons within two days. Mild depressions of white cells and platelets in some persons
1.25-2.00	Symptomatic course with transient disability and clear hematologic changes in a majority of exposed persons. Lymphocyte depression of about 50% within 48 hours
2.40-3.40	Serious, disabling illness in most persons, with about 50% mortality if untreated. Lymphocyte depression of about 75% within 48 hours
5.00+	Accelerated version of acute radiation syndrome, with gastrointestinal complications within 2 weeks, bleeding and death in most exposed persons
50.00+	Fulminating course, with cardiovascular gastrointestinal, and CNS complications resulting in death within 24 to 72 hours

Initial or prodromal symptoms occur from about 1 to 6 hours after a significant acute exposure. The typical symptoms which occur following whole body doses: anorexia, 0.2 Gy; nausea, 0.75 Gy; vomiting, 1 Gy; and diarrhea, 1.5 Gy. The presence or lack of nausea and vomiting within three hours of exposure tends to separate the high dose (possibly fatal) from low dose (probably non-fatal) categories. Within a few hours or days, if supralethal dose was not received, there follows a relatively symptom-free latent period which lasts up to 3 weeks. A shorter latent period occurs at higher doses. It is followed by the period of manifest illness, with the characteristic signs and symptoms of anorexia, fatigue, malaise, epilation, fever, infections, stomatitis, and hemorrhagic

phenomena. In addition, to these effects of bone marrow depression there are the characteristic signs and symptoms of the particular organ systems involved, leading to either a fatal outcome or recovery. The prognosis for whole body doses <2.0 Gy is excellent, >6.0 Gy 90-100% is fatal, and the prognosis declines with the addition of a traumatic injury [Vo 94].

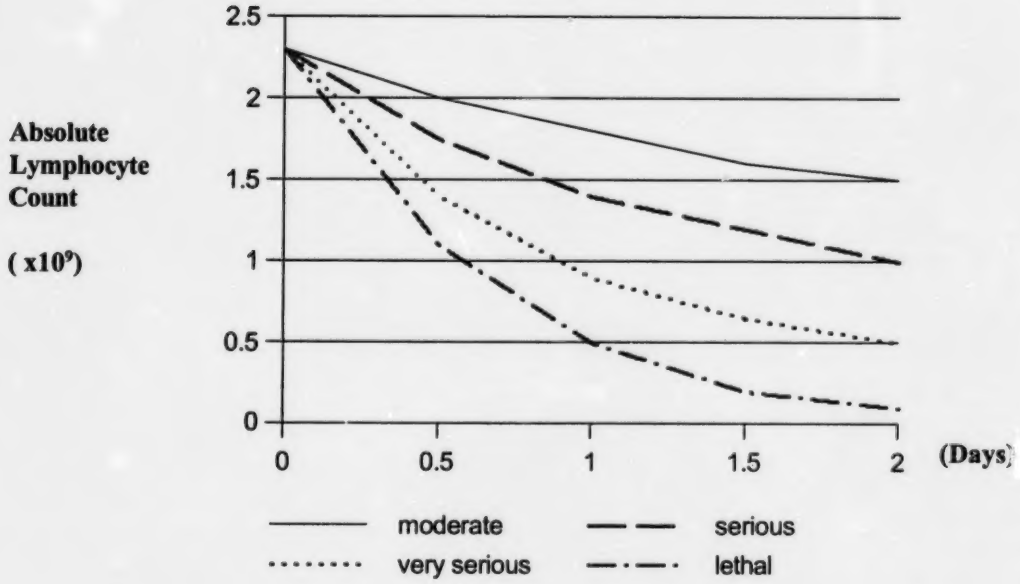
Another indicator of severity is the presence of skin erythema which can occur within minutes to hours after an exposure of several Gy. Epilation occurs at doses exceeding 3 Gy, and it occurs rather abruptly about the seventeenth day post exposure.

If there are 1200 or more lymphocytes per cubic millimetre in a peripheral blood sample at 48 hours post exposure, the likelihood of survival is very good. Less than 500 suggests a poor prognosis. Failure of the total leukocyte count to level off or temporarily rise during day 8 to 20, is a poor prognostic sign. After the syndrome passes through the nadir of bone marrow depression, the blood elements begin to recover, with full restoration in 6 months or less, except that the lymphocyte count may remain sub-normal for several years. Andrews et al. show the patterns of early lymphocyte response in relation to dose (Figure 3) as well as the values for each of the blood elements in fairly severe haematopoietic syndrome (Figure 4).

In cases of relatively uniform whole body irradiation cytogenetic analysis of peripheral lymphocytes is the most sensitive laboratory test for detecting a clinical biologic response to ionizing radiation. Doses down to 0.15 Gy can be detected, but with some uncertainty. At the mid-lethal doses the method is particularly useful for verification of doses in this range. Blood for lymphocyte culture should be sampled as early as possible and the number of chromosome aberrations compared with an appropriate reference curve, established from *in vitro* irradiation of whole blood with a corresponding radiation under standardized conditions.

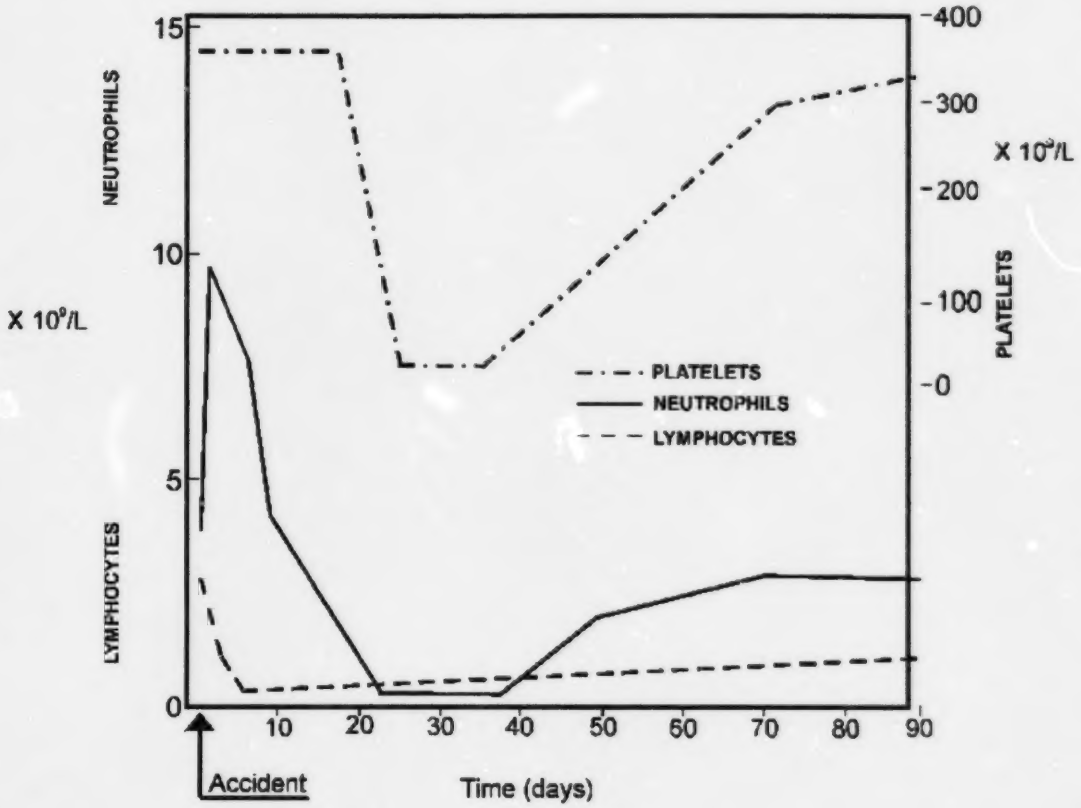
The dose needed to result in permanent sterility from testicular irradiation varies considerably: reports suggest that a dose as small as 2 Gy is sufficient but most reports are in the range of 5-6 Gy. The United Nations Scientific Committee on the Effects of Ionizing Radiation have concluded the following:
(1) temporary sterility of the testes is reported to occur with single doses ranging from 1.5 to 4 Gy and with fractionated doses of 0.1 to 2 Gy;
(2) permanent sterility occurs with single doses ranging from 5 to 9.5 Gy and with fractionated doses of 2 to 6 Gy.
Changes in sperm count from an acute exposure appear in about 30-60 days. The testes differ from other organs in that the same dose spread out over time tends to cause more, not less damage. Temporary sterility may continue for a number of years following exposure.

Figure 3: Patterns of early lymphocyte response in relation to dose



(Taken from Andrews 1973 [An73])

Figure 4: Peripheral blood changes following moderate whole body iradiation



(Taken from IAEA-TECDOC-366 [IA86])

LOCAL RADIATION INJURIES

Localized exposure occurs when a small area of the body, usually the extremities, is irradiated from exposure to a narrow beam or by holding a radiation source. If sufficient bone marrow is spared from irradiation, acute radiation syndrome will not result.

An initial symptom of heat, the onset of pains and paraesthesia, and disturbances to tactile and heat sensitivity are commonly reported. The symptom of heat depends upon the dose and dose rate. Pain is described as constant, very intense, and perceived as burning. In serious cases it can be resistant to analgesics. There are four typical patterns of injury [NC74]:

Type I: Erythema only, this is equivalent to a first degree thermal burn, like a mild sunburn. The threshold dose for 3 cm diameter fields is between 3 and 10 Gy. The delay in the appearance of signs and symptoms is dependent upon the dose, typically for lower doses it may be 2-3 weeks.

Type II: Transepidermal injury (wet desquamation), is equivalent to the injury seen in a thermal burn of the second degree. After erythema develops, blisters form and break open, leaving raw, painful wounds vulnerable to infection. The symptom free period is shorter than in Type I and blisters appear within 1-2 weeks depending on the dose. Threshold doses are in the order of 10 to 20 Gy. These lesions usually heal with care, but the new skin is usually pigmented, thin and easily injured. Marked local edema can occur and, with tendon and synovial surface involvement, can restrict motion.

Type III: Dermal radionecrosis is caused by doses exceeding 20 Gy. The lesions resemble those cause by a severe scalding; pain occurs promptly and is intense. Amputation is required for necrosis and failure of skin grafting.

Type IV: Chronic radiation dermatitis arises from repeated or continuous exposure of the skin to beta, gamma or x-rays over a period of months or years. This eczema-like condition seldom heals, frequently ulcerates and predisposes to skin cancer.

Distribution, nature (particulate or electromagnetic), and energy of radiation are important considerations in determining the extent of the injury and lack of repair due to radiation arteritis and circulatory impairment. In general, particulate radiation of less than 10 MeV is of low penetration producing superficial injuries involving only the dermis. In spite of the intense local injury, the clinical and laboratory findings are minimal. Late effects which may be expected are those resulting from insidious but progressive tissue atrophy, fibrosis and chronic radiodermatitis with tissue breakdown.

Table 7: Patterns of Local Radiation Injury

Type	Signs & Symptoms	Threshold	Remarks
I	Erythema	3-10 Gy	Appears 2-3 weeks
II	Erythema & blisters	10-20 Gy	Appears 1-2 weeks, usually heal
III	Necrosis	> 20 Gy	Dermal radionecrosis, amputation likely
IV	Eczema	Chronic Exposure	Seldom heals, predisposes to ulceration and skin cancer

(Taken from NCRP Report #42 [NC74])

RISK ESTIMATES

It is asssumed that any increase in radiation exposure will result in a proportional increase in radiation-induced cancer. This assumption is difficult to prove, however. An increased risk of cancer has been shown in Japanese atomic bomb survivors exposed acutely to more than 0.005 Sv [Pi96]. Effects other than cancer have been observed only at high doses and are generally assumed to be threshold effects.

Estimates of cancer risk are mainly based on epidemiological studies of human populations exposed to high doses of radiation. These include the Atomic Bomb Survivors, occupationally exposed persons and patients who were exposed to ionizing radiation for medical treatment. The degree of risk at doses lower than this is not likely a straight line extrapolation. Based on the human epidemiologic studies, animal experimentation and mathematical modelling, risk coefficients have been calculated for the excess cancer mortality attributable to ionizing radiation. A **dose rate reduction factor** has been applied to the risk estimates derived from these studies to take into account the low levels and protracted exposure in occupational exposures. The International Commission on Radiological Protection (ICRP) used these coefficients to estimate a nominal value of 5×10^{-2}/Sv for the lifetime probability of induced fatal cancer in a population of all ages (the general public), and 4×10^{-2}/Sv for a working age population (occupational). The lifetime risk for fatal and weighted non-fatal cancers and hereditary effects is 7.3×10^{-2}/Sv per sievert.

The estimated lifetime risk for dying of cancer is 27% in Canada. Thus, for 10,000 persons, 2700 would be expected to die of cancer. If all 10,000 persons were exposed to radiation (0.01 Sv/person) one would expect 5 extra cancer deaths. Of course, on an individual basis the risk is relative to the individual`s age, sex and baseline cancer risk.

Ionizing radiation can produce gene mutation and chromosome aberrations. If the individual gene is in a germ cell of the testis or ovary, this damage can be transmitted as a heritable mutation. The BEIR V Committee [BE90] concluded upon review of the evidence that the **doubling dose** in humans is likely no smaller than 1 Sv. The doubling dose is the radiation dose that would double the incidence of spontaneous genetic defects in an exposed population.

Some epidemiological work has been conducted in Canada using occupationally exposed workers because they are expected to have higher exposures than those which might be received by members of the general public. For example, a cohort mortality study using the records of the National Dose Registy reported an excesss relative risk of 3% per 10 mSv (90% C.I. 1.1-4.8) for all cancers combined. This is within the range of risk estimates previously reported in the literature. This cohort consisted of over 200,000 individuals monitored between 1951 and 1983 [As98]. Ontario Power Generation Inc. reported their corporation's mortality experience in a series of reports. Death from cancer was less than that in men of similar ages in the general population. A similar observation was found in an analysis of mortality among Atomic Energy Canada Limited workers during the 1950-1981 period [Ho87]. Another analysis of cancer mortality in this cohort during the period 1956-1985 showed an excess relative risk of 0.36% [Gr 93] for all cancers. The authors concluded that risk estimates based on high-dose studies are unlikely to underestimate risks substantially for low-dose and low-dose-rate exposures.

The risk of cancer incidence in relation to exposure to radiation is also being studied at Ontario Power Generation Inc. and the National Dose Registry. The Ontario Power Generation study will be a case-control study with cases taken from the Ontario Cancer Registry and dose information from Ontario Power Generation Inc.'s Radiation Dose Information System.

In addition to the study of cancer risk, studies have attempted to evaluate the risk of sequelae to children from exposed parents. A study, soon to be published, will evaluate the risk of having a child with a congenital anomaly in relation to occupational exposure to ionizing radiation in the period before conception. This case control study is based on the Canadian Congenital Anomalies Registry and uses record linkage techniques to identify congenital anomalies among offspring of Ontario Power Generation workers. The risk of congenital anomaly is assessed in relation to parental exposure to quantitative estimates of radiation dose acquired through work within a nuclear generating station.

Probability of Causation

There has been an increase in the claims made by cancer victims for compensation due to ionizing radiation exposure. However, it is not yet possible to precisely identify the cause of a particular malignancy. An approach based on risk estimates derived from epidemiological studies estimate the probability that a particular malignancy may have been caused by a specified radiation exposure (PC). If the radiation dose to an individual can be determined then the PC can be calculated using a formula. The PC is estimated from the ratio of the increased incidence of a malignancy attributable to the specified radiation exposure to the sum of the spontaneous malignancy rate and the increase attributable to the specific radiation exposure.

It should be remembered that this method estimates probability; it does not provide proof of causation. There are many uncertainties in the risk estimates used in the calculation and this method assumes that the individual is of average susceptibility. It does not take into account exposures to other carcinogens or risk factors. Uncertainties can be reduced somewhat by using data appropriate to the individual such as age, sex, time since exposure, type of malignancy, etc.

IN WHAT WORKPLACES MIGHT RADIONUCLIDES BE ENCOUNTERED?

Where radionuclides are encountered in the workplace
- Fuel cycle
- Industry
- Teaching and research
- Medicine
- Natural sources of radiation

Typical activities of commonly used industrial radionuclides

Description of commonly used radionuclides by source

WHERE RADIONUCLIDES ARE ENCOUNTERED IN THE WORKPLACE

FUEL CYCLE

Uranium mining and milling

Open pit or underground techniques are used to remove uranium ore which is then crushed and ground. This is followed by chemical leaching, separation of uranium, and precipitation of U_3O_8, known as yellowcake. The remaining rock, or tailings, is discharged to a holding pond and neutralized. A barium compound is used to precipitate out radium-226 which could otherwise leach into the ground water.

Workers can receive internal and external exposures from these processes. Internal exposure is mainly due to inhalation of radon gas and its decay products in the underground mines, and ore dust containing radioactive particles (mainly U-238 and other alpha emitters in this decay chain). The radiological hazards in the uranium industry are discussed in more detail elsewhere [AC98, Sa91, AI81]

Uranium refining

Refining begins with the addition of nitric acid to yellowcake to form uranyl nitrate and through a series of chemical steps uranium dioxide (UO_2) is produced. Although these processes occur in sealed environments, workers can be exposed during maintenance and in the event of leaks. However, it should be remembered that soluble uranium compounds are generally more toxic chemically than radiologically.

Fuel fabrication

Fuel fabrication is the process of converting uranium dioxide into a physical form suitable for use in the reactor. Uranium dioxide powder is pressed, sintered into hard pellets, ground, then loaded into fuel rods usually made of a zirconium alloy.

During fuel fabrication the primary source of exposure is from uranium, as most decay products have been removed in the preceding processes. The dose rate from gamma radiation is relatively low compared with the dose rate from beta radiation. Actual exposures tend to be low due to engineered controls.

Reactor operation

Tritium (H-3) is the most significant internal radiation hazard in a CANDU nuclear generating station, typically contributing 30% of staff radiation dose. It arises during the operating life of the reactor in both the moderator and coolant systems that contain heavy water (D_2O). Tritium emits a low energy beta particle which requires specialized instruments for its detection (most are designed to measure gamma radiation or high energy beta). While the low energy beta particle cannot penetrate the outer layer of intact skin, as water vapour (HTO), it enters the body through the lungs, gut and the skin, rapidly dispersing throughout the body. Station staff wear plastic suits with supplied air in

atmospheres containing tritium. Tritium can now be removed from the heavy water, decreasing this hazard significantly.

Carbon-14 is another low energy beta emitter which is generated in the CANDU reactor primarily by reactions with oxygen-17 in oxide fuels, moderator and coolant, and reactions with nitrogen-14 in fuel. Most of the carbon-14 produced in the moderator system and in the primary heat transport system is held on ion exchange resins which filters these heavy water systems or in the fuel (>90%) while about 4% is released in the atmosphere from predominantly the moderator cover gas. Monitored releases to atmosphere can occur during purging of the system cover gas. Periodically the resin material is removed from the reactor and stored locally or at waste disposal sites. These in turn are potential sources for atmospheric release. Once the carbon-14 becomes airborne as carbon-14 dioxide, it can also become dispersed in the environment [AC95]. Carbon-14 dioxide readily interacts with vegetation through the process of photosynthesis and is thus incorporated into the carbon cycle.

Other internal exposures could arise due to inhalation of rare gases or particulates released in aerosol form. There are a number of possibilities which could arise due to relatively minor accidents in the course of normal station operation. These include corrosion products (cobalt-60, iron-56), activation products (carbon-14, zirconium-95), and fission products (cesium, strontium and iodine-131). All of these are released from time-to-time at the stations. Of a more serious nature are releases from severe fuel or core damage.

In the unexpected event of a nuclear reactor accident involving a loss of coolant, fission products have a potential to be released from the fuel in the fuel bundle. Should releases occur, they are generally released into containment so they should not pose an immediate internal hazard unless someone was unfortunate enough to be caught inside containment or there was a release from containment into the reactor auxiliary bay. The fission process generates a very large number of isotopes. Modelling suggests that those of high relative abundance and high radiobiological significance are cesium and iodine isotopes, bound together chemically, primarily in the form of cesium iodide, cesium hydroxide, and other metal oxides with some degree of volatility (barium, molybdenum, ruthenium, strontium and lanthanum).

WHERE RADIONUCLIDES ARE ENCOUNTERED IN THE WORKPLACE

INDUSTRY

There are many industrial applications for radionuclides. The industries associated with the highest potential doses to workers are industrial radiography, well logging, luminizing, and radioisotope production. Some other common uses of radionuclides will be discussed because, even though the doses from normal handling are very small, they do have the potential to give rise to significant accidental exposures. A list is provided with information on typical activities of commonly used industrial radioisotopes.

Industrial radiography

Industrial radiography is a form of non-destructive testing which utilizes gamma radiation from a radioactive source. The source is passed through a sample under investigation (e.g., pipes, concrete floors) and the emergent beam is recorded on film. Flaws in the sample (e.g., cracks, voids, inclusions) attenuate the beam to a different extent than the sample material, and show up as detail on the film.

All exposure devices utilize a shielded container to hold the source when not in use. The exposure of an operator of a device can depend on its design. Exposure devices fall into the following categories: crank operated, pneumatic, crawlers and beam-type. In the beam-type, for example, the source does not leave its container, but is exposed by moving it in front of a window where the shielding has been removed. These devices help to minimize operator exposure.

As an occupational group, industrial radiographers have the highest exposures [HC97]. Commonly used sources are Ir-192 and Co-60 [As97].

Oil and gas well logging and tracing

Both sealed and unsealed sources of radioisotopes are used in oil exploration and production.

Oil and gas is usually found in rock formations which resemble a sponge, the petroleum product being trapped under pressure in the hollow spaces. When a well is first drilled, the reservoir pressure forces the oil or gas through the sponge-like rock toward the borehole and thence to the surface. As the oil is extracted the reservoir pressure drops and eventually a point is reached where the oil will not flow through the formation under it own pressure. At this point the oil company can stimulate the well to obtain a secondary recovery of oil.

One method of stimulation is called formation fracturing. This process uses high pressure liquid to fracture the rock formation and provide additional pathways for the oil or gas to reach the borehole. In order to ensure that the fractures occur at the correct location a small amount of radioactively tagged sand (usually Ir-192) is added to the main stream going down the well and a detector lowered down the hole afterward can find the fractures.

A tertiary recovery of oil is also possible because many wells are usually drilled into the same formation. If water, steam, or solvent is injected into the well, the material will flow through the rock formation, sweeping oil in front of it, towards the boreholes of the other wells. To determine the efficiency of the system, a tracer is added to the injected fluid and relative amounts of tracer found at each well are measured. Tracer is usually added directly at the injection well head, either using an external pressure source such as compressed gas or an electric pump, or by utilizing the differential pressure across the choke valve on the injection system itself. Isotopes used in oil and gas well tracing vary greatly but H-3, Cs-137, Cs-134, and Co-60 are commonly used.

Sealed sources are used in the oil and coal industries to provide information about underground geological formation. These devices are enclosed in a tool which is lowered down the borehole on a wire line. Also enclosed is a sensitive detector which measures the radiation scattered back by the rock formation. The scattered radiation is analyzed by computers on the surface. Sources used in this work include Cs-137 and Co-60, as well as neutron emitters like Am-241\Be.

Luminizing

The majority of self-luminous devices, such as exit signs and air craft landing lights use tritium to excite the phosphor in a glass tube. Small calibration sources use C-14. Historically Ra-226 was used for watches and instrument dials.

Radioisotope production

Radioisotopes are increasingly used in medicine and industry. They are produced by reactors or cyclotrons, then processed into the desired compound. The main source of occupational exposure in the manufacture or processing of radioisotopes is external radiation. In some cases internal exposure may also be significant.

Static eliminators

Static eliminators use sealed radioisotope sources, Po-210 and Am-241, to ionize air in areas where unwanted static electricity builds up, thereby allowing static charge to leak off.

Smoke detectors

Smoke detectors use sealed radioisotope sources. In the presence of combustion products a current carried by a beam of alpha particles is interrupted, thereby initiating an alarm. Am-241 is commonly used in household detectors. Ra-226 was used in older detectors.

Gauges

These devices use sealed radioisotope sources to measure specific characteristics of a material under test. Fixed gauges are usually attached to process equipment in an industrial setting to measure density of a material in nearby pipes, vessels, or moving webs. The source, usually a gamma emitter such as Cs-137, is located on one side of the material being tested while the detector is located on the other side. The amount of attenuation of the gamma radiation is directly proportional to the density of the material.

Portable gauges such as moisture/density gauges can be used to measure compaction of soil, stone, or asphalt in road beds and moisture content of almost any solid. Portable gauges can house two sources to measure two parameters at once. For example, a gamma source, such as Cs-137, can be used to measure the density of any road bed, while a Am-241 /Be source can be used to measure moisture or asphalt content. The Am-241/Be source is a neutron source. Any hydrogenous material present will slow down or thermalize the neutrons. These thermal neutrons can be measured as backscatter and the signal is proportional to the amount of hydrogenous material present.

Electron capture detection

This process is used in gas chromatographs, laboratory instruments which can separate a mixture of gases into their component parts. A sealed beta source is used to provide a beam of electrons inside the detector volumes. When gases are separated and exit the separation column, they pass through the detector. When the detector volume is empty it emits a steady electrical signal. When a gas enters a detector some of the electrons are captured by the gas and the electrical signal is altered. This perturbation is measured and is proportional to the amount of gas present.

Radiation sterilization

High energy gamma radiation, usually from a sealed Co-60 source is used to sterilize a wide range of materials. Laboratory models use a heavily shielded source and human access is impossible in the design configuration. Commercial sterilizing plants, on the other hand, utilize a source which is stored in a pool of water. During operation the source is raised and the space above becomes the irradiated area. Human access to the irradiated area must be strictly controlled to prevent radiation exposure.

WHERE RADIONUCLIDES ARE ENCOUNTERED IN THE WORKPLACE

TEACHING AND RESEARCH

Many institutions use radioactive material for both teaching and research purposes. Some institutions teach industrial radiography but most use relatively small quantities of unsealed sources, usually tracers, for teaching biological or medical disciplines. Almost any radioisotope can be used in these studies but common biological tracers are H-3, P-32, S-35, while nuclear medicine training utilizes radioisotopes such as Tc-99m, and Ga-67. Volatile radioisotopes are not frequently used in research. I-125, used for labelling, is volatile, but not used frequently.
The more common radioisotopes, H-3, P-32, and S-35 are used in non-volatile form on open benches.

WHERE RADIONUCLIDES ARE ENCOUNTERED IN THE WORKPLACE

MEDICINE

Hospitals and clinics use a variety of sealed and unsealed sources for diagnosis and treatment.

Nuclear medicine in its simplest form is the functional imaging and treatment of human disease. This is accomplished with the utilization of a radioactive molecule that either allows identification of a disease process or aids in its treatment.

Nuclear medicine started as an imaging speciality approximately 30 years ago with the clinical utilization of radioactive iodine (I-131) in the diagnosis and treatment of thyroid disorders. Over this time span the equipment used to image patients has dramatically improved as has the variety of agents used to both diagnose and treat patients. The vast majority of nuclear medicine clinical services are in the diagnosis of disease involving virtually all body systems. Bone scans (Sr-89, Tc-99m, PET F-18), cardiac studies (Th-201, Tc-99m), renal flow examinations (Tc-99m), brain scans (PET F-18), lung scans (Tc-99m) and pulmonary diffusion studies (C-14) are only a few of the widespread modalities available to study the human condition. These tests are based on functional imaging that reveal the way the body works both in health and in disease. The vast majority of studies involve an injection of a small amount of radioactive material with imaging obtained after the radioactivity is distributed within the body. The doses administered tend to be under 1 GBq and because of the short half-lives involved, the radiation burden to the patient is quite small. With very few exceptions, nuclear medicine imaging, and in fact most imaging , for pregnant patients is safe but normal precautions are instituted to avoid or minimize fetal exposure.

Occasionally, therapy using unsealed sources is called for and the classic case is the treatment of an overactive thyroid or of thyroid cancer with radioactive iodine taken internally. More recently there has been new interest in the treatment of bone metastases with a variety of beta emitting agents such as strontium. In these particular cases the purpose of therapy is to deliver a large radiation exposure to specific target areas and therefore the radiation exposure to the patient is necessarily much higher. This, however, is to the general benefit of the patient.

High activity sealed sources, such as Co-60 in teletherapy devices and in brachytherapy are used in cancer treatment. Human access is controlled during operation but in the rare event of an accident, the exposure could be high.

WHERE RADIONUCLIDES ARE ENCOUNTERED IN THE WORKPLACE

NATURAL SOURCES

Naturally occurring radioactive materials can become concentrated by man's activities and are a source of occupational and environmental radiation exposure.

Underground mines

Coal and other mineral underground miners are exposed to enhanced levels of natural background radiation, primarily radon and its decay products [UN93]. Uranium mines were mentioned earlier.

Oil and gas industry

In the oil and gas industry, the amount of naturally occurring material brought to the surface generally increases with the amount of water pumped from the underground geological formation containing oil and gas. As the water is brought to the surface with oil and gas, its temperature and pressure changes and it may deposit radioactive scale and sludge in the equipment.

Uranium and thorium are found in varying concentrations in these underground geological formations but they are relatively insoluble and remain underground when water is brought to the surface. However, radium and radium progeny (decay products of uranium and thorium) are slightly soluble and can be found dissolved at low levels or precipitated out in the scale and sludge. Scales found on production equipment typically contain radium coprecipitated in barium sulphate.

The most affected workers in the industry are oil and gas field operators, maintenance crews (well servicing), and equipment cleaners.

Fertilizer industry

Rock containing phosphate is used as the raw material for the production of ammonium phosphate fertilizers. The phosphate rock has trace levels of radioactive impurities such as U-238 and Th-232 and their progeny (Ra-226, Rn-222 are of particular interest). Because of the chemical processing of rock, U-238 and Th-232 are found in trace amounts in the fertilizer, while Ra-226 is found in the phosphogypsum product. Scale and sludge containing Ra-226 can also build up in the processing equipment.

Workers in the industry most likely exposed to scale and sludge are phosphoric acid operations technicians and maintenance technicians.

A number of independent research studies are underway in Canada to explore the use of phosphogypsum. It has potential application in agriculture and construction. For workers, this means the potential for direct radiation exposure and inhalation of phosphogypsum associated radionuclides.

TYPICAL ACTIVITIES OF COMMONLY USED INDUSTRIAL RADIONUCLIDES

Sealed Sources:

Americium-241 (typically up to 37 GBq per source)
Americium-241/Beryllium (up to 740 GBq per source)
Cesium-137 (typically up to 370 GBq per source, although some irradiators contain much larger sources)
Cobalt-60 (up to 3700 GBq for common industrial use, but the large commercial irradiators contain up to 111 PBq
Iridium-192 (up to 3700 GBq per source)
Krypton-85 (up to 56 GBq per source)
Nickel-63 (up to 555 MBq per source)
Polonium-210 (up to 7400 MBq per source)
Strontium-90 (up to 296 GBq per source)

(SI unit prefixes : M = 10^6, G = 10^9, T = 10^{12}, P = 10^{15})

Open Sources:

Antimony-124 (typical possession limit 74 GBq)
Bromine-82 (typical possession limit 18 GBq)
Cesium-134 (NOTE: not Cs-137)(typical possession limit 74 GBq)
Cobalt-60 (typical possession limit 74 GBq)
Hydrogen-3 (typical possession limit 74 TBq)
Iodine-131 (typical possession limit 37 GBq)
Iridium-192 (typical possession limit 111 GBq)
Krypton-85 (typical possession limit 740 GBq)
Nickel-63 (typical possession limit 185 GBq)
Scandium-46 (typical possession limit 37 GBq)
Sodium-24 (typical possession limit 18 GBq)

(SI unit prefixes : M = 10^6, G = 10^9, T = 10^{12}, P = 10^{15})

DESCRIPTION OF COMMONLY USED RADIONUCLIDES BY SOURCE

Sealed sources:

Cs-137

Sealed sources up to 370 GBq are used in fixed gauging applications. There are thousands of these devices used throughout Canada, mainly in the steel, paper and bottling industries (about 700 licensees). Larger sources, up to 740 GBq are used by about 35 licensees in the well logging industry. Cs-137 is also used in brachytherapy for the treatment of cancer.

Ir-192

Sources up to 3700 GBq are used in industrial radiography. This application of radioisotopes employs only about 3% of radiation workers in Canada, but results in almost 70% of absorbed dose to radiation workers (about 140 licensees). Ir-192 is also used in brachytherapy for the treatment of cancer.

Po-210

Strip-sources up to 7400 MBq are used extensively for static elimination devices. There are about 90 licensees in Canada.

Americium-241 (as Am-241/Be neutron sources)

These sources are mainly used in portable moisture/density gauges. Source size is up to 1850 MBq, and there are about 500 licensees in Canada. Larger sources, up to 740 GBq, are used in the well logging industry.

Cobalt-60

Co-60 is used in industrial or laboratory irradiators. The large commercial sterilizers contain up to 148 PBq, while the laboratory models contain about 1 PBq. There are four of the former installations in Canada, and 34 of the latter. Co-60 is also used in teletherapy units for the treatment of cancer.

Nickel-63

400 licensees use electron capture detectors containing up to 555 MBq of Ni-63 in sealed form.

Open sources:

Open-source isotopes are used by pharmaceutical companies and private research facilities. They are not used very frequently in the industrial sector but some of the applications follow:

Ni-63, Tc-99 (not 99m), H-3, Br-82, Kr-85

Used as tracers in industrial processes like refineries and paper mills. Up to 3700 MBq can be injected per study. Three companies are licensed to do this work in Canada.

Ir-192, Sc-46, Sb-124

Used as tracers during a "well fracturing" operation. In a large fracturing job, 3700 MBq could be injected into an oil well. Three companies are licensed to do this work in Canada.

WHERE CAN I OBTAIN MORE INFORMATION ABOUT SPECIFIC RADIONUCLIDES?

Introduction

Because of the wide variety of both medical and industrial needs involving radioactivity there are a wide diversity of radioisotopes that provide useful and sometimes vital information in the course of our occupations. Luckily, adverse contamination of humans with radionuclides is a very rare event [NC79, Me90]. However, in those rare occasions where accidental exposure of workers to radioactive materials occurs this directory of specific radioisotopes is meant to act as an initial source of reference. Hopefully the references provided will yield more specific diagnostic and therapeutic avenues to explore.

Americium	Am-241
Half-life :	458 years
Primary Emissions:	Alpha particles, 26 and 60 keV gammas
Absorption Routes:	inhalation, direct wound contamination
Principal Retention Sites:	liver and bone
Therapy:	iv DTPA (diethylenetriaminepentaaceticacid) wound excision and washing with DTPA

Americium does not occur naturally. It has several isotopes but its principal one, Am-241, is a daughter product of plutonium-241 and is found frequently with plutonium processing or handling. Am-241 has a physical half-life of 458 years and an effective half-life in bone of 140 years. The assumed effective half-life in the whole body is 150 years and within the liver, 20 years [IC88]. Am-241 decays primarily by emitting alpha particles and photons (gamma rays) of energies 26 and 60 keV . The most common use for Am-241 is as a radiation source for static eliminators, smoke detectors, thickness gauges and calibration sources. In the early days of dual photon bone mineral densitometry it was used as one of the primary energy sources. Combined with beryllium, americium is often used as a neutron source.

Americium is generally only accumulated within the body either through direct instillation through wounds or by inhalation. There is very little, if any, absorption when administered through the gastrointestinal tract [Du73]. Absorption through intact skin is thought to be limited but probably, as with plutonium, is increased when it is dissolved in solutions having an acidity that destroy the integrity of the skin barrier.

In industry, inhalation of particles is an important internal exposure route. Uptake depends markedly on the chemical and physical properties of the particulates, as with any aerosol. Rat studies indicate that 75 to 85% of the initial lung burden is absorbed into the body, with about 10% retained in the lungs, and less than 15% is cleared from the lung by normal mucocillary transport and excreted in the faeces.

Once absorbed, americium is deposited primarily within the liver and skeleton with lesser amounts initially present in the kidney and spleen. In animals, the skeleton is probably the critical organ for long-term effects due to the longer effective half-life in bone compared to other organs. The liver is

also an organ of concern. The greatest long-term doses, however, are generally received by the tracheobronchial lymph nodes, liver, lung and then bone.

The treatment for internal deposition of americium regardless of the route of exposure is the immediate administration of a metal chelate typically DTPA (diethylenetriaminepenta-acetate) or its related material EDTA. In the event of a contaminated puncture the local area should be excised promptly since the absorption rate of americium can be rapid (over 50% in the first day). Dogs that were given EDTA had a liver content that was reduced by a factor of 200 for a treatment interval of 203 days as opposed to a control dog where the reduction factor was only 3 over the same time period. A typical human dose for this treatment would be approximately 1 gm of DTPA daily. As with most therapies early administration is important for effectiveness [Se75, Se76, Co76]. Other studies have revealed that even late treatment with chelates enhances clearance of activity from the body. With regards to its toxicity Am-241 is an classified as a Class 1 (very high toxicity) agent by the International Atomic Energy Agency.

Carbon	C-14
Half-life:	5730 years
Primary Emissions:	157 keV beta
Absorption Routes:	lung, GI tract, and skin
Principal Retention Sites:	all tissues
Therapy:	for most forms of exposure no treatment is available

The two principle isotopes of carbon are C-11 and C-14. C-11 is a positron (positively charged electron) emitter with a half-life of 20.3 minutes and a mean positron particle energy of 394 keV. C-14 is strictly a low energy beta emitter with a maximal energy of 157 keV but an extremely long physical half-life of 5,730 years. This is one of the principal reasons why C-14 dating is so popular. It is only actively accumulated during the life-time of the specimen to be dated and therefore, upon death, the amount of C-14 remaining within the specimen gives a good indicator of the approximate age at time of death.

C-11 is primarily used in clinical positron emission tomography sites for the specific analysis of a variety of imaging compounds. Because of its extremely short half-life, problems with overdose are extremely rare and self-limiting. Generally by the time any sort of treatment for potential overdose can be instituted the activity is already substantially decreased.

C-14, because of its long half-life, causes additional problems. Its beta energy is low enough, however, that the beta particle generally does not penetrate past the dead layer of skin cells. About 10% of the surface dose rate reaches the germinal layer of the skin. Clinically it is used for marking a wide variety of biological compounds in biochemistry labs and in nuclear medicine is used for a variety of breath tests as well as lactose absorption tests. If absorbed into the body either through oral absorption or direct penetration of the skin, treatment is generally restricted to the area of entry (excision). This agent is primarily used as a tracer in the laboratory and is a product of the CANDU system. It is quite unusual to find large amounts of C-14 that could pose a health hazard.

Cesium Cs-137

Half-life:	30 years
Primary Emissions:	510 keV beta and 662 keV gamma
Absorption Routes:	lung, skin, GI tract
Principal Retention Sites:	all tissues esp. muscles
Therapy:	decrease absorption

Cesium is an alkaline metal. Cs-137 with a half-life of 30 years and Cs-134 with a half-life of 2.1 years are the most likely ones to be encountered occupationally. Cs-137 decays by emitting beta particles of 510 keV and 662 keV gamma rays from its daughter product.

Cs-134 decays by emitting beta particles of energies ranging from 90 to 1450 keV- the most abundant being 650 keV. It also emits a range of gamma rays wth energies from 480 to 1370 keV.

Cs-137 is an important fission fragment produced by either uranium or plutonium fuels. It has been the subject of many radiobiological and metabolic studies because it is one of the longer physical half-life fission products found in the environment and in man as a result of worldwide fall-out associated with atmospheric weapons testing. It was also an important fall-out contaminant during the Chernobyl accident. In industry it is used as a sealed gamma source for thickness gauges, and, in medicine and research, it is used as a sealed source for cancer therapy, and very rarely, as a tracer substance.

Cesium has very similar chemical and biochemical properties to potassium and therefore a similar biological distribution. After ingestion, cesium is rapidly absorbed with about 10% being excreted by the kidneys during the first two days. The subsequent biological half-life is approximately 109 days. The biological half-life, however, is much shorter in children and is also generally shorter in women [Ll66].

The most effective means of removing radioactive cesium in man is by the oral administration of ferric cyanoferrate (II) commonly called Prussian Blue. Although it is not available as an approved drug in North America it has been found to be relatively harmless and well tolerated by man [NC77]. Prussian Blue is not absorbed from the intestine and it binds the cesium ions that are routinely cycled into the gastrointestinal tract so that the cesium is not reabsorbed. Biological half-life during such treatment is reduced to about one third of its usual value and the total body burden is therefore similarly reduced. Recently, hemodialysis has been proposed to rapidly extract radioactive cesium from the bloodstream but this is probably limited to acute exposure situations [Ve95].

Cobalt Co-60

Half-life:	5.3 years
Primary Emissions:	313 keV beta, 1170 and 1330 keV gammas
Absorption Routes:	inhalation and GI absorption; little by direct skin contact
Principal Retention Sites:	liver and other tissues
Therapy:	iv DTPA

Cobalt radioisotopes most likely to be encountered are the forms Co-60, Co-58, and Co-57. Co-60 has a physical half-life of 5.3 years and decays by emitting a 310 keV beta particle and 1170 and 1330 keV gamma rays. The other isotopes have shorter physical half-lives, Co-57 being 271 days and Co-58, 71 days. Both decay with gamma emissions.

Co-60 sealed sources are used in medial radiation therapy and in industrial radiography. It has been used in industry for thickness gauges, calibration sources and tracers. In nuclear medicine applications, the Co-57 isotopes have been used primarily for labelling vitamin B12 in the performance of Schillings tests and as a calibration source as "mock technetium".

Human exposures generally have been incurred by inhalation of particles which are better evaluated by whole body counting rather than by measuring cobalt activity in the urine. After inhalation exposure there is prompt excretion in the urine with about 80% being eliminated in a biological half-life of one day or less.

There have been no cases of significant human radiation exposure resulting from internal deposition of cobalt. Theoretically, stomach lavage may be helpful for ingestion and the role of chelating drugs is not certain.

Gold	Au-198
Half-life:	2.7 days
Primary Emissions:	970 keV beta and 412 keV gamma
Absorption Routes:	GI absorption (10%), limited skin penetration, inhalation unknown
Principal Retention Sites:	liver, kidneys, reticuloendothelial system
Therapy:	dimercaprol and penicillamine have been tried to increase urine excretion

Gold-198 is the only widely used radioisotope of gold. It is used in medical therapy, biological research, and occasionally as a calibration source. Au- 198 emits 970 keV beta particles and 412 keV gamma rays. Its physical half- life is 2.7 days. For medical uses, Au-198 was primarily used in the colloidal form for the palliative management of malignant pleural, abdominal and pericardial effusions. Approximately 90% of the radiation dose is delivered by the beta particles which have a mean penetration of about 0.4 millimetres and a maximum penetration of less than 4 millimetres in tissues. When non-colloidal Au-198 is taken by mouth about 10% is absorbed into the blood of which one-quarter goes into the liver and kidneys. When colloidal gold-198 is injected intravenously its effective half-life is 2.6 days with the majority accumulating in the reticuloendothelial system cells of the liver, spleen and bone marrow. Colloidal Au-198 is also administered as an intra articular instillation.

There is no known therapy for internal intake Au-198 colloid once the particles are phagocytosed by the reticuloendothelial cells. Subsequent possible bone marrow failure might be treated with transfusions of suitable blood components. For ionic gold, dimercaprol or penicillamine may be tried although the short effective half-life of Au-198 suggests that the dose reduction would be limited.

Indium	In-111
Half-life:	2.38 days
Primary Emissions:	171 and 245 keV gammas
Principal Retention Sites:	Kidney, spleen
Therapy:	DTPA

Indium-111 is commonly used in medicine to label a wide variety of biological products including white blood cells, somatostatin and DTPA as a CSF imaging material. It has a physical half-life of 67 hours and decays by emitting 171 and 245 keV gamma rays. Most indium containing compounds are already complexed with DTPA and will be fairly rapidly excreted within the urine. If an overexposure of indium is suspected, intravenous treatment with either EDTA or DTPA may help clear this metal ion.

Iodine	I-131
Half-life:	8.04 days
Primary Emissions:	610 keV beta, 364 keV gamma
Absorption Routes:	lung, GI tract and skin
Principal Retention Sites:	thyroid and urinary excretion
Therapy:	non-radioactive iodine to compete with radioactive iodine

There are more than 20 radioactive isotopes of iodine. Some very important radioisotopes are found in industry and medicine. I-131 is the dominant radioisotope contributing to internal exposure after a reactor accident, nuclear weapons test or any incident involving fresh fission products [Ro66]. However, short-lived radioisotopes I-132, I-133, I-134, I-135 with half-lives from 52 minutes to 6.7 hours can contribute significantly if the person is in close proximity to a fresh fission product release.

I-131 warrants further discussion as the radioactive iodine of significance in postulated CANDU accidents as it is relatively abundant, volatile, and has a relatively long half-life compared to the short-lived radioisotopes of iodine. Exposure can occur principally two ways, from the inhalation of radioactive iodine in the plume of radioactivity from the reactor and the ingestion of food which has become contaminated by fallout from the plume [GM95a]. When extensive environmental contamination occurs, contamination of the milk supply by cattle grazing on contaminated grass lands can be a major problem. In such cases, the physician may be called upon to advise the patients on the safety of drinking milk after a reactor accident. In general there is about a five day effective half-life of Iodine-131 in vegetation [FR64]. Emergency reference levels have been suggested to determine when counter measures may be indicated. These levels are 925 Bq/l as the peak level on milk and 5550 Bq/m^2 on a pasture [Br69].

I-131 has a physical half-life of 8.1 days and an effective half-life in humans of about 7.6 days. It decays by emitting beta particles, the predominant one being 610 keV. In laboratory uses of I-131, small exposures generally occur as the result of inhalation but ingestion through mouth pipetting and absorption through the skin have been reported.

I-125 has a physical half-life of 60 days and decays by emitting gamma rays in the 27-36 keV range. It is used for labelling and occurs in a volatile form.

Radioactive iodine is rapidly and effectively absorbed by the thyroid in most normal individuals. Other sources of prominent uptake occur within the salivary glands, stomach mucosa, and genitourinary tract. For normal individuals approximately 10 to 30% accumulates within the thyroid 24 hours after exposure. This has important medical applications for the evaluation of both hypothyroidism and hyperthyroidism. I-131 is often administered therapeutically to achieve hypothyroidism in a number of medical conditions.

The external detection of significant contamination of I-131 can easily be made using an uptake probe at most nuclear medicine hospital departments. Individuals who have had an accidental occupational exposure to radioactive iodine regardless of the route of administration, or isotope, should immediately receive stable potassium iodide compounds to provide approximately 100 mg of stable iodine. Uptake of I-131 can be effectively blocked if potassium iodide is taken promptly after an accidental exposure. Tablets are available but 5 or 6 drops of supersaturated solution of potassium iodide (Lugol's solution) is an alternative way to provide a competing source of stable iodine. Daily administration of potassium iodide or other agent may need to be continued for several days, depending on the situation.

Individuals exposed to large concentrations of radioactive iodine will need to be followed for the possible eventual development of hypothyroidism which may take up to 2 years to be identified. Usually, however, reduction in patient hormone levels will be seen by 6 weeks post accidental ingestion. There is also an increased risk of developing thyroid cancer from the radiation exposure many year later.

Iridium Ir-192

Half-life: 74 days

Primary Emissions: 536 and 672 keV betas, 316 and 468 keV gammas

Iridium-192 is produced by neutron bombardment in a reactor and is used in industrial radiography or occasionally in medical therapy as a brachytherapy source. It has a relatively short physical half-life of 74 days with a variety of emission. The principal emissions are 536 and 672 keV beta particles and 316 and 468 keV gammas.

Nickel Ni-63

Half-life: 96 years

Primary Emissions: 66 keV beta

Principal Retention Sites: lung and CNS tissue

Nickel-63 is a reactor produced material that is commonly used as a foil source or in gas chromatography. It has a physical half-life of 96 years with almost total beta emission at 66 keV. Nickel by itself is moderately toxic and has been a suspected carcinogen. It does accumulate within lung tissue as well as the central nervous system. Treatment for suspected radioactive nickel exposure is limited to topical treatments. Little is known about the systemic treatment for nickel overexposure.

Phosphorus P-32

Half-life: 14.2 days

Primary Emissions: 1710 keV beta

Absorption Routes: lung, GI tract and skin

Principal Retention Sites: bone and bone marrow

Therapy: non-radioactive phosphate, PTH, gastric lavage, copper sulfite by mouth

The first radioactive isotope to be prepared in a cyclotron was P-32. The physical half-life of P-32 is 14.2 days and it decays by emitting an energetic beta particle with a maximal energy of 1710 keV. The beta particle has a maximal range in tissue of 7 millimetres. Because P-32 only releases beta particles it has proven to be of value in medical therapy.

Phosphorus is an essential element in living cells and in standard man comprises 1.1% of the total body weight. Tissues with rapid cellular turnover also show a higher retention of phosphorus as it is accumulated in the nuclear proteins. P-32 has a long biological half-life of approximately 257 days for the whole body and 1155 days for bone, which makes the effective half-life about the same as its physical half-life of 14 days.

The main uses of P-32 are in medical therapy, biochemical research, industry and agricultural research. Although once used in the diagnosis of intraocular, intracranial, skin and breast tumors it is now primarily used in the treatment of polycythemia rubra vera as a solution of sodium phosphate given intravenously and occasionally as an anti-arthritic synovial ablation material given intra articularly, and in the treatment of malignant pleural effusion or ascites.

Overdosage with P-32 would primarily affect the bone marrow with characteristic falls of white and red blood cell lines. Therapy could consist of non-radioactive phosphate given by mouth orally as well as a parathyroid extract given intramuscularly every six hours. If the overdosage is identified promptly gastric lavage with potassium permanganate (1:5000) or 3% hydrogen peroxide would be helpful. Copper sulfite which forms an insoluble copper phosphide could be given orally in a dose of 0.25 gm. Mineral oil as well as aluminum or magnesium hydroxide may also help prevent gastrointestinal absorption.

Plutonium Pu-239

Half-life:	24,400 days
Primary Emissions:	alpha (5.11, 5.16 MeV)
Absorption Routes:	inhalation
Principal Retention Sites:	lung, lymph nodes, liver, bone
Therapy:	DTPA

Plutonium is a man-made element which has numerous isotopes, all of which are radioactive. Pu-238 and Pu-239 are the most iikely to be encountered in occupational settings, but not commonly in Canada. Pu-239 is used in some countries as a fissile fuel in nuclear explosives and for generating heat in power production. The CANDU system does not utilize Pu-239 for power production. Pu-238 has also been used as a power source in certain applications, ie., satellites, nuclear powered pacemakers, etc. It is possible that plutonium will be encountered more often in Canadian research institutions: research is planned to test the ability of the CANDU system to utilize weapons grade plutonium in a mixed type of fuel. The objective is to find ways of reducing the global availability of weapons grade plutonium.

Pu-239 is an alpha emitter with a physical half-life of 24,400 years. It has the ability of fissioning when exposed to slow neutrons. The principal alpha particles have energies of 5.16 and 5.11 MeV. Pu-238 is also an alpha emitter with an 86 year half-life. The principal alpha particles have energies of 5.46 and 5.5 MeV.

Plutonium has high chemical reactivity and can be incorporated into many chemicals with different properties and particle sizes. Plutonium dioxide is probably the most important compund because of its use as a nuclear fuel. Even the biological behavoir of plutonium dioxide can vary considerably depending on the exact chemical composition, particle size and shape. Generally plutonium is not absorbed through the skin and poorly absorbed though the digestive tract. Inhalation is the primary route of signficiant plutonium deposition. The alpha radiation also does not penetrate the basal layer of the skin. The radiation becomes important only when inhalation has occurred and the plutonium is aerodynamically able to reach the alveolar region of the lung. There it is retained where it irradiates the lung, or is systemically redistributed. "Soluble" plutonium clears from the lung within a year or two and translocates primarily to the liver and bone. "Insoluble" plutonium will be retained longer and translocates primarily to the regional lymph nodes.

Accidental intake of plutonium can be treated with chelating agents such as DTPA.Contaminated wound are best treated by surgically removing the tissues adjacent to the contaminated wounds.

Polonium	Po-210
Half-life:	138 days
Primary Emissions:	alpha (5.8 MeV)
Absorption Routes:	lung, GI tract and skin
Principal Retention Sites:	spleen and kidneys
Therapy:	dimercaprol

Polonium-210 was used extensively in early atomic weapons manufacture and later was employed briefly in thermal electric generators and space satellites. The first communication satellite was actually powered by a Po-210 source. The atmosphere normally contains polonium as it is a decay product of Ra-226, naturally occurring within the earth's crust. Increased contributions have been added by manmade activities such as burning fossil fuels, nuclear weapons testing, and radiation disasters. Cigarettes have been found to contain Po-210 and it has been suggested as a possible cause of lung cancer [Ma64]. Po-210 is one of the last radioactive members of the uranium decay scheme and therefore has been extensively studied in uranium miners. After years of exposure, about 78% of the body burden will be found in the skeleton with other important deposits within the lung, liver and muscle tissues. Polonium decays by alpha emission with a physical half-life of about 138 days. Its biological half-life is approximately 40 days. Critical organs are considered to be the spleen and kidneys. Acute Po-210 intake has resulted in 20 times greater excretion in the faeces rather than the urine.

Dimercaprol has been suggested as a treatment and should be given intramuscularly. Neither DTPA or EDTA appear to be effective in treating internal contamination with polonium [Fo58].

Radium	Ra-226
Half-life:	1600 years
Primary Emissions:	alpha (4.6 and 4.8 MeV), 186 keV gamma
Absorption Routes:	lung, GI tract, and skin
Principal Retention Sites:	bone
Therapy:	calcium gluconate and amonium chloride

Radium-226 is a naturally occurring radioactive element that occurs in several major series of natural radioactive decay. Ra-226 is a principal decay product of U-238 and has a physical half-life of 1620 years. It decays to radon-222 by emitting alpha particles of energies 4.56 MeV and 4.78 MeV).

Ra-226 has been used primarily in medical practice in the treatment of cancer by insertion of encapsulated needle sources directly into the tumor or by means of moulded applicators that hold the source next to the tumor. Industrial applications have included application for luminous paints.

After oral ingestion about 30% of the radium is absorbed. The majority of the activity however is excreted in the feces with a small percentage being excreted in the urine. Radium remaining within the body is almost totally deposited within the skeleton. Follow-up studies in nearly 300 radium dial painters who used to tip their brush with their tongues found several types of malignant tumors including osteogenic sarcomas, fibrous sarcomas, carcinoma of the paranasal sinuses and mastoids, leukemia, and aplastic anemia. Accumulative skeletal radiation doses below 1000 rads were not associated with clinically significant radiobiological injury which covered a time span of 40 to 50 years or more [Ha69, Ev74].

Immediate stomach lavage with a 10% magnesium sulphate solution is recommended for patients who have recently ingested radium.

Radon

Half-life:	3.8 days
Primary Emissions:	alpha (5.4 MeV) and 510 keV gamma
Absorption Routes:	inhalation
Principal Retention Sites:	lung
Therapy:	-

Radon-222 is a naturally-occurring colourless, odourless, radioactive gas formed by the radioactive decay of radium-226 in the earth. It enters dwellings via cracks in basement walls. When ventilation is poor radon tends to accumulate. Its concentration is greater in basements. The concentration of radon varies significantly over time, being worse in the winter months when ventilation is poorer. Human exposure to radon varies considerably.

Radon gas and its progeny decay by emitting alpha particles. Only internal irradiation is important. As a gas, radon is inhaled and tissues in the respiratory tract are preferentially irradiated because the range of alpha particles is short.

Radon has been shown to be a carcinogen in laboratory animals. Uranium miners who are exposed to radon progeny in their work have shown an increased risk of lung cancer, after adjusting for other lung cancer causing risk factors. Miner data form the basis for predicting lung cancer risk from indoor radon exposure. However, studies of radon exposure in homes have not conclusively demonstrated that an increased risk of lung cancer exists.

Combined exposure to tobacco smoke and high levels of radon leads to greater than additive effects for lung cancer. A joint analysis of uranium miner studies indicates that the relative risk is 3-fold higher in smokers than in non-smokers [Lu94]. Clearly smoking cessation will considerably reduce the risk of lung cancer.

The federal government has established guidelines for radon exposure in homes; above 800 Bq/m^3 remedial action is recommended. There are several methods available for reducing the level of radon in a dwelling.

Strontium Sr-90

Half-life: 29.1 years

Primary Emissions: 540 keV beta

Absorption Routes: lung, GI tract and skin

Principal Retention Sites: bone

Therapy: non-radioactive strontium lactate, oral or IV calcium gluconate, acidification with ammonium chloride. Barium sulfate, calcium alginate and aluminum phosphate when given orally reduce absorption. Potassium rhodizonate is useful for open wounds.

Strontium-90 is a fission product of uranium. Several of its radioisotopes have proven useful. Of note is Sr-90, which has a long physical half-life of 28 years and decays with a 540 keV beta particle. This gives rise to Y-90 which also emits a 2250 keV beta particle. Sr-89 has a physical half-life of 51 days and decays by emitting a 1460 keV beta particle as well as a very small percentage of 910 keV gamma rays.

Sr-90 has been used in the treatment of cutaneous lesions that are only a few millimetres in depth. Sources have been used in industry for thickness gauges by measuring the beta ray backscatter from sheets of paper, rubber or metal. Occasionally Sr-90 was also used in luminous dial applications. Large amounts are occasionally used for thermal electric sources in buoys and similar devices when long lived independent power sources are required. Sr-85 has been used in the past in medical as well as agricultural research. In nuclear medicine it was used for the initial evaluation of strontium metabolism and formed one of the earliest bone scan materials.

Sr-89 has recently enjoyed a resurgence in popularity as an intravenous therapy for painful osseous metastases. The biological half-life of strontium in man is found to be less than 250 days after a single oral ingestion. The biological half-life from an intravenous injection is longer, averaging about 843 days. Inhalation results in biological half-life of 500 days. The amount of strontium that has accidentally entered the human body can be determined by a single 24-hour urinary measurement of excreted strontium [Sa65].

Immediately after ingestion aluminum phosphate can reduce absorption by as much as 85% and is considered the drug of choice. Barium sulphate is a risk free alternative drug that also causes significant reduction in intestinal absorption. After intravenous or inhalation absorption of radioactive strontium several compounds of stable strontium can be used to dilute the uptake of radioactive strontium but of course it must be given shortly after exposure.

Technetium Tc-99m

Half-life: 6.02 hours

Primary Emissions: 140 keV gamma

Absorption Routes: lung, GI tract and skin

Principal Retention Sites: thyroid, stomach, GU tract

Therapy: oral potassium perchlorate

Technetium has several radioactive isotopes but by far the most common and widely used, particularly in nuclear medicine, is metastable Tc-99m. It was selected and introduced because of its suitability to diagnostic imaging with a desirable gamma emission of 140 keV and a short physical half-life of 6.0 hours. Tc-99m results from the decay of Mo-99 which has a 67 hour physical half-life. Technetium in the pertechnetate form has a very short biological half-life of just one day for the whole body, 20 days in the kidney and up to 30 days in the liver. Pertechnetate is actively concentrated in the thyroid gland, salivary glands, stomach, and genitourinary tract. However, in nuclear medicine the majority of applications using technetium often depend on its ability to form complex compounds to determine its biodistribution. For example, when technetium is bound to sulphur colloid it acts as a liver/spleen scanning agent, but when it is bound to sestamibi acts as a cardiac imaging preparation. Because of its very short half-life and almost exclusive gamma emission it is unlikely that there will be any patients accidentally overexposed to Tc-99m who would require therapy. The administration of potassium perchlorate is effective in partially displacing pertechnetate-99m ions from sites of concentration within the thyroid gland, salivary glands, and stomach [An65]. Occupational exposures are almost entirely external.

Tritium (Hydrogen 3)	H-3
Half-life:	12.3 years
Primary Emissions:	18 keV beta
Absorption Routes:	lung, GI tract and skin (as water)
Principal Retention Sites:	all tissues
Therapy:	force fluids, rarely hemodialysis

Tritium is the only radioactive isotope of hydrogen. It decays by emitting a beta particle with a maximal energy of 18 keV. Its physical half- life is 12.3 years. Small amounts of the isotope are normally present in the atmosphere being produced by cosmic ray reactions with nitrogen. Atomic weapons testing has increased the tritium present in the environment.

While tritium has not been used extensively in clinical medicine it did enjoy minimal use in total body water measurements and *in vivo* labelling of proliferating cells by injection of tritium labelled thymidine. Probably the most active current clinical use is in the tracing and bioassays of small amounts of biological compounds in radio-immune assays. Industrially, tritium is used as a target material in accelerators for production and moderation of fast neutrons. It is occasionally used as a radiation source in thickness gauges and has found some commercial use in making luminous paints. Tritium is the most significant internal radiation hazard in a CANDU nuclear generating station, typically contributing 30% of staff radiation dose. It arises during the operating life of the reactor in both the moderator and coolant systems that contain heavy water.

While the low energy beta particle cannot penetrate the outer layer of intact skin, tritiated water vapour (HTO) may enter the body through the lungs, gut and skin, rapidly dispersing throughout the body. Radiological control requires periodic biological monitoring of workers through measurements of tritium in urine. Tritium contamination of surfaces including skin are very difficult to measure because of the low energy beta particles. Health effects related to a single dose of tritium, however, have not been reported in literature.

While the physical half-life of tritium is 12.3 years, the biological half-life is 10-12 days. As soon as an acute exposure is recognized, the individual should void immediately, this sample being saved as a control. All subsequent voidings are to be monitored for tritium. After a single acute exposure a peak urine concentration of 37 MBq/l (1 mCi/l) of tritium is roughly equivalent to a whole body dose of about 31 mSv (3100 mrem) without treatment. Treatment consists of forcing fluids to tolerance to dilute the tritium and increase diuresis. With 3 to 4 litres per day, one can anticipate reducing the half-life by 50% [GM95].

Uranium	U-238
Half-life:	4.5×10^9 years
Primary Emissions:	Alpha, beta, gamma
Absorption Routes:	Lung, GI tract, skin, eyes, wounds
Principal Retention Sites:	Bone, lung (kidney is a critical organ for chemical toxicity)
Therapy:	Reduce absorption, stimulate excretion

Uranium only occurs in radioactive form. Natural uranium is a mixture of U-238 (99.3%), U-235 (0.7%) and U-234 (0.006%). U-238 is the head of the uranium/radium radioactive decay series and U-235 begins the uranium/actinium series. The isotopes of natural uranium all have extremely long physical half-lives and its decay products emit alpha, beta and gamma radiations. Each of the isotopes also undergo spontaneous fission at low rates. Two decay products include the gases radon-222 and radon-219 which are found in uranium and other mines. Radon's decay products adhere to atmospheric dust particles and constitute an inhalation health hazard.

Various uranium compounds can be encountered by workers at various stages of the nuclear fuel cycle - mining, milling, refining, conversion and fuel fabrication. Details on the sources of exposure and radiation monitoring of uranium workers can be found elsewhere [AC98].

Uranium can be considered a chemical or radiological hazard depending on its isotopic composition and transportability within the body. For natural uranium, it is the total amount of metal absorbed which determines its toxicity. Since most of the absorbed uranium is excreted by the kidney, it is the kidney which first shows signs of chemical damage, ie., proteinuria.
The critical organ for less soluble uranium, especially if enriched with U-235, is likely to be bone, or, when inhaled, the lung. Readers are advised to consult with experts when attempting to assess the occupational hazards associated with uranium exposure.

Repeated measurements of urinary excretion of uranium is recommended for assessing single large exposures, especially when the solubility of the uranium compound is known. Whole body (or lung) counting is the best method of assessing body burdens of inhaled insoluble uranium compounds.

Treatment of accidental intakes of uranium is aimed at reducing absorption and stimulating excretion.

LOCAL, NATIONAL AND INTERNATIONAL SOURCES OF INFORMATION

Radiation Trauma Unit

The Radiation Trauma Unit of the Toronto Hospital is equipped to manage victims of radiation accidents from nuclear facilities (416) 603-5800, ext. 5098.

Health Canada

Health Canada periodically produces reports on environmental radioactivity in Canada and on occupational radiation exposures. These may be obtained by writing to the address below or on internet at http://www/datahpb/dataehd/english/catalog/rpb_pubs/index.htm. Enquiries on specific topics in radiation protection (monitoring, bioassay, whole body counting, chromosome analysis, occupational exposures, health effects, x-rays, non-ionizing radiation) may be directed to the Radiation Protection Bureau, 775 Brookfield Road, Ottawa, Ontario K1A 1C1 (613) 954-6647.

Atomic Energy Control Board

The Atomic Energy Control Board publishes documents related to its regulatory activities in the nuclear power industry and use of radioisotopes. Documents are available free of charge from the Office of Public Information, Atomic Energy Control Board, P.O. Box 1046, Ottawa, Ontario K1P 5S9 (613) 995-5894 or (800) 668-5284. For emergencies, the 24 hour Duty Officer telephone number is 613-995-0479.

National Dose Registry

The Canadian National Dose Registry (NDR) maintains radiation dose records of all radiation workers in Canada. The NDR regularly publishes information on occupational exposure to radiation. An individual may also apply for a copy of his dose record by calling (613) 954-6660.

National Radiological Protection Board

National Radiological Protection Board in the United Kingdom produces many reports on radiological safety. A catalogue may be obtained from NRPB, Chilton, Didcot, Oxon, OX11 0RQ United Kingdom.

National Council on Radiation Protection and Measurements

National Council on Radiation Protection and Measurements is a non-profit corporation which disseminates information about protection against radiation and radiation measurements. NCRP publications are distributed by the NCRP Publications' office at 7910 Woodmount Avenue, Suite 800, Bethesda, MD, USA 20814-3095

International Commission on Radiological Protection

International Commission on Radiological Protection is an international body which recommends radiation protection standards. The scientific basis for its recommendations are published in the Annals of ICRP by Pergammon Press, Headington Hill Hall, Oxford, OX3 OBW, United Kingdom.

International Atomic Energy Agency

International Atomic Energy Agency produces numerous reports on the peaceful uses of nuclear technology. Its publications are available from the Division of Publications, International Atomic Energy Agency, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria or through Renouf Books, 1294 Algoma Road, Gloucester, Ontario K1B 3W8 (613) 741-4333.

United Nations Scientific Committee on the Effects of Atomic Radiation

The United Nations Scientific Committee on the Effects of Atomic Radiation was established by the General Assembly of the United Nations in 1955. It produces reports on the sources and effects of radiation. These are available through Renouf Books, 1294 Algoma Road, Gloucester, Ontario K1B 3W8 (613) 741-4333.

TECHNICAL RESOURCES

Human Monitoring and Bioassay Capabilities

- transuranics
- fission products
- strontium-90
-carbon-14
-tritium
- uranium

Dicentric chromosome analysis

Procedures for collecting blood for chromosomal analysis

DTPA and Prussian Blue

Procedure for obtaining DTPA and Prussian Blue

HUMAN MONITORING AND BIOASSAY CAPABILITIES

Health Canada's National Calibration Reference Centre for Bioassay and *In vivo* Monitoring has the capability to measure individuals to evaluate the risk from occupational or environmental exposure to internally deposited radionuclides.

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: TRANSURANICS

British Columbia
University of British Columbia (3,4)[2]

Alberta
ARCT Chemtech, Calgary (3,4)

Saskatchewan
University of Regina (3,4)

Manitoba
Manitoba Cancer Research and Treatment Foundation (2,3,4)
Department of Fisheries Fresh Water Institute (3)

Ontario
Ontario Hydro - Tiverton (4)
Exploranium (1)
Radiation Protection Bureau (1)

1 This list is extracted from a survey report prepared for Health Canada in 1996 entitled, "National Inventory of Nuclear Emergency Response Capabilities". This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included.

2 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: FISSION PRODUCTS

<u>British Columbia</u>
Simon Fraser University (1,2,3,4)[2]
University of British Columbia -TRIUMPH (2)
University of British Columbia (3,4)
British Columbia Ministry of Health (3,4)

<u>Saskatchewan</u>
University of Regina (2,3,4)
University of Saskatchewan (2)

<u>Alberta</u>
Calgary General Hospital (1,2,3,4)
Alberta Labour, Edmonton (2)
University of Calgary (2)
South Alberta Institute of Technology (3)

<u>Manitoba</u>
Manitoba Cancer Research and Treatment Foundation (2,3,4)
Department of Fisheries Fresh Water Institute (3)

<u>Ontario</u>
McMaster University (1,2)
Ontario Hydro -Whitby (1,2,3,4)
Ontario Hydro - Tiverton (1,2)
Exploranium (1)
North Bay General Hospital (1,2,3,4)
Ottawa Civic Hospital (1,2,3)
Mount Sinai Hospital, Toronto (2,3,4)
University of Toronto (2)
Radiation Protection Bureau (1,2,3,4)

<u>Quebec</u>
Hôpital Laval (1,2,3,4)
Hydro Québec (1,2,3,4)
McGill University (2)
Hôpital Général de Montréal (2)
Royal Victoria Hospital, Montreal (2)
Concordia University (3,4)

<u>New Brunswick</u>
New Brunswick Power- Lepreau (1,2,3)
New Brunswick Power- Fredericton (3)
Saint John Regional Hospital (2)
Queen Elizabeth Health Sciences Centre (2)

<u>Nova Scotia</u>
Aberdeen Hospital*, New Glasglow (1,2)
Valley Regional Hospital, Kentville (1)
Cape Breton Regional Hospital (1,2)
Western Regional Health Centre, Yarmouth (2,3)
Dr. Georges Dumont Hospital, Halifax (2)

<u>Prince Edward Island</u>
Queen Elizabeth Hospital (1,2)

[1] This list is extracted from a survey prepared for Health Canada in 1996 entitled, "National Inventory of Nuclear Emergency Response Capabilities". The Ontario Ministry of Labour has been removed from the above list as it no longer provide this service. This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included. In many institutions the "fission product" category is limited to I-131.

[2] 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: STRONTIUM-90

British Columbia
Simon Fraser University (3,4)[2]
University of British Columbia (3,4)
British Columbia Ministry of Health (3,4)

Alberta
ARCT Chemtech (3,4))

Manitoba
Manitoba Cancer Research and Treatment Foundation (2,3,4)
Department of Fisheries Fresh Water Institute (3)

Ontario
Ontario Hydro - Tiverton (3)
University of Toronto (3)
Radiation Protection Bureau (3)

Quebec
Hydro Québec (3)
McGill University (3)
Concordia University (3)

1 This list is extracted from a survey report prepared for Health Canada in 1996 entitled, "National Inventory of Nuclear Emergency Response Capabilities". This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included.

2 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: CARBON-14

British Columbia
Simon Fraser University (3,4)[2]
University of British Columbia (3,4)

Saskatchewan
University of Regina (3,4)

Alberta
ARCT Chemtech (3,4)
University of Lethbridge (3)

Manitoba
Manitoba Cancer Research and Treatment Foundation (3,4)
Department of Fisheries-Freshwater Institute (3)

Ontario
McMaster University (3)
Ontario Hydro- Whitby (3)
Ontario Hydro-Tiverton (3)
University of Toronto (3)
Radiation Protection Bureau (3)

Québec
Hôpital Laval (3)
Hydro Québec (3,4)
McGill University (3)
Concordia University (3)

New Brunswick
New Brunswick Power-Lepreau (3)

1 This list is extracted from a report prepared for Health Canada in 1996 entitled "National Inventory of Nuclear Emergency Response Capabilities". This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included.

2 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: TRITIUM

<u>British Columbia</u> Simon Fraser University (3,4)[2] University of British Columbia -TRIUMPH (3) University of British Columbia (3,4) <u>Alberta</u> University of Lethbridge (3) ARCT Chemtech (3,4) <u>Ontario</u> McMaster University (3) Ontario Hydro -Whitby (3) Ontario Hydro - Tiverton (3) Mount Sinai Hospital, Toronto (3,4) University of Toronto (3) Radiation Protection Bureau (3)	<u>Quebec</u> Hôpital Laval (3) Hydro Québec (3,4) McGill University (3) Concordia University (3) <u>New Brunswick</u> New Brunswick Power- Lepreau (3) New Brunswick Power- Fredericton (3)

1 This list is extracted from a survey report prepared for Health Canada in 1996 entitled, "National Inventory of Nuclear Emergency Response Capabilities". The Ontario Ministry of Labour has been removed from this list as it no longer provides this service. This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included.

2 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

HUMAN MONITORING AND BIOASSAY CAPABILITIES[1]: URANIUM

Saskatchewan
Saskatchewan Research Council (3)[2]

Alberta
ARCT Chemtech (3,4)

Ontario
Exploranium (1)
University of Regina (3,4)
Radiation Protection Bureau (3,4)

1 This list is extracted from a survey report prepared for Health Canada in 1996 entitled, "National Inventory of Nuclear Emergency Response Capabilities". The Ontario Ministry of Labour has been removed from this list as it no longer provides this service. This is not an exhaustive list and only those institutions that did not indicate in the survey that their response was confidential are included.

2 1 - Whole body Counting, 2 - Thyroid, 3 - Urine/Blood, 4 - Feces

PRUSSIAN BLUE AND DTPA

In Canada, Prussian Blue (Ferrihexacyano-ferrate) is not authorized for use in humans. It is commercially available in non-pharmaceutical grade for laboratory use. Pharmaceutical grade Prussian Blue can be obtained from the manufacturer, HEYL, in Germany, with the authorization of the Emergency Drug Release Program of Health Canada. Alternatively, the distributor in the U.S., RMC Medical may be approached in the same manner. The procedure is provided below. The typical dosage of Prussian blue is 1 gm t.i.d. for several days delivered by mouth in 100-200 ml water.

DTPA (calcium trisodium pentetate) is not authorized for sale as a chelating agent in Canada. The same procedure needs to be followed as for ordering Prussian Blue, above. It can also be obtained from HEYL. The typical dosage is 1 gm CaDPTA in 500 ml 5% D/W i.v. over 60 minutes, or 1 gm in 6 ml 5% D/w slow i.v. (1 minute). This may be administered 1-5 days per week as long as enhanced excretion of radionuclide makes it worthwhile.

If these drugs are not already stocked at the time of an accident, it may be worthwhile to seek alternate sources due to the delay in obtaining the drug from the manufacturer. In case of urgent need some possible sources are the, Toronto Hospital Radiation Traum Unit , the
Atomic Energy of Canada Limited in Chalk River (DTPA only), and the U.S. Radiation Emergency Assistance Centre/Training Site at Oak Ridge, Tennessee (423) 576-3131.

PROCEDURE FOR ORDERING PRUSSIAN BLUE OR DTPA

When ordering Prussian Blue from the Emergency Drug Release Program (EDRP) for emergency supply:

1. FAX, telephone or write to EDRP to request emergency drug.
   Emergency Drug Release Program
   Human Prescription Drugs
   Holland Cross, Tower B
   1600 Scott Street, 3rd floor
   Ottawa, Ontario K1A 1B8

   (613) 941-2108 (08:30-16:30 EST)
   (613) 941-3061 (after hours)
   (613) 941-3194 (FAX)

2. Authorization may be granted. EDRP notifies the manufacturer of the drug by telephone. This verbal authorization is followed up by a Letter of Authorization which is sent to the manufacturer and copied to the physician.

3. The following information needs to be supplied by a physician when the drug is requested:
   - physician's name and telephone number
   - address of physician's office or hospital pharmacy where drug is to be distributed
   - drug name and dosage form
   - manufacturer's name, address, telephone and contact person's name:

     Dr. Wolfgang Parr,
     Managing Director, Distribution Department
     HEYL Chemisch-pharmazeutische Fabrik GmbH & Co. KG
     Goerzallee 253
     D-14167 Berlin (Zehlendorf)
     Germany
     Tel: (030) 8169611
     FAX: (030) 8174049

   - total quantity of the drug requested
   - intended dosage
   - medical indication for use
   - if the drug is to be stored for emergency use, no patient needs to be named, but this must be explained

Note: For the first supply of drugs ordered by one institution, the Emergency Drug Release program can authorize sale of drugs without an actual patient being named at that time.

The address of the U.S. distributor for HEYL is RMC Medical, 3021 Darnell Road, Philadelphia, PA 19154 USA (215) 824-1300.

DICENTRIC CHROMOSOME ANALYSIS

This technique is not readily available in Canada and can be quite costly. It can be performed by the Radiation Protection Bureau of Health Canada, whose protocol is provided below. The cost for the kit alone (for one specimen) is approximately $500. This procedure is also commercially available from: Geoffrey Schofield Laboratory, Westlakes Science & Technology Park, Moor Row, Cumbria, CA24 3JZ, U.K.; and the U.K. National Radiological Protection Board.

Analysis of chromosomal aberrations in human peripheral blood is the present day standard for assessing chromosomal damage from acute radiation exposure. Dose estimates are based on frequencies of dicentric chromosomes. Although the dicentric is an easy aberration to identify it is unstable and therefore of little use in quantifying chronic exposures or those occurring a long time ago. Blood may be taken for the assessment of an acute exposure up to nine months after the exposure occurred. This technique is presently not practical for expected whole body doses less than 150-200 mSv. The value of this technique in the assessment of partial body exposures is also uncertain.

Other techniques for assessing radiation damage exist but standard reference curves have not yet been developed. Fluorescence *in situ* hybridization analysis can be used for translocation detection. This is a stable aberration and can potentially be used to assess long term exposures. The single cell assay measures DNA damage more directly than dicentric analysis. It measures an important effect of radiation on lymphocytes called apoptosis but the period over which damage can be measured is probably limited to only a few days.

PROCEDURES FOR COLLECTING BLOOD FOR CHROMOSOMAL ANALYSIS

Analysis of chromosomal aberrations in Human peripheral blood is the present day standard for assesing chromosomal damage from radiation exposure. This assay is highly dependent upon the capability of peripheral blood cells (T lymphocytes) to be stimulated by a mitogen to initiate reproduction. To optimize viable cell recovery from irradiated patients and minimize the need for repeated sampling, it is very important that the blood be collected and shipped according to protocol.

Prior to collecting samples, please notify the Radiation Protection Bureau, at the number provided below, so that preparations can be made for arrival and pick up of the sample.

All blood samples are to be collected, under sterile conditions, into sodium heparin (at least 30 ml per patient), and gently rocked for 2 min to ensure proper mixing. At the same time acquire as much medical information as possible from the patient, including known exposures to any mutagens (ie., diagnostic radiation exposure, chemotherapeutic agents, cigarette smoke). Exposures within the last two years are of great importance since they may be contributing to assessed cumulative damage.

Package all samples so that they are maintained at room temperature, and ensure that the samples do not freeze during transportation (e.g., Air mail). External package labelling should emphasize that the samples should not be frozen upon transportation.

For shipment of samples use overnight delivery. Contact the Bureau to confirm the shipment and provide the **Way Bill** tracking number.

For best results blood must be received within 24 hours of collection.

NOTE: The culturing and assessment of samples for chromosomal aberrations requires approximately three weeks. If this patient has received previous medical treatment, as mentioned above, the culturing of T lymphocytes may be jeopardised, resulting in low yields and inconclusive results.

For further information contact:

Diana Wilkinson, Ph.D
Radiation Protection Bureau
775 Brookfield Rd.
Ottawa, Ont. K1A 1C1
Tel: 1- 613-941-8516
FAX: 1-613-941-1734
E-mail: d_wilkinson@hc-sc.gc.ca

WHERE CAN I GET TRAINING?

Oak Ridge Institute for Science and Education

Pat Cooley
Registrar, REAC/TS
P.O. Box 117
Oak Ridge, TN 37831-0117
(423) 576-3131

Several Courses offered:

Handling of Radiation Accidents: This course emphasizes the practical aspects of handling a contaminated victim by discussing the fundamental of radiation, how to detect and measure it, how to prevent the spread of contamination, how to reduce the radiation dose to the victim and attending personnel, and the role of the medical/health physicist in caring for contaminated accident victims.

Occupational Health in Nuclear Facilities: This course presents information on basic radiation sciences, health surveillance and evaluations, on-site emergency management of injuries, and medical implications of chemical, physical, biological, social and psychological stressors on the ability to work.

Health Physics in Radiation Accidents: The major topics covered are radiological emergency procedures and the role of the health physicist in a medical environment.

Medical Planning and Care in Radiation Accidents: This course presents an advances level of information on the diagnosis and treatment of acute local and total body radiation exposure, internal and external contamination, combined injuries and multicasualty incidents involving ionizing radiation.

Harvard School of Public Health

Office of Continuing Education
Harvard School of Public Health
677 Huntington Ave.
Boston, MA
02115-6023
Tel: 617-432-1171
Fax: 617-432-1969
E-Mail: contedu@sph.harvard.edu
http://www.hsph.harvard.edu/CCPE/ccpe.html

Occupational and Environmental Radiation Protection
(offered twice yearly)

Session Topics include radiation sources, units, concepts, biological effects, measurement techniques, internal and external dosimetry, management and disposal of low-level radioactive waste, and applicable standards.

National Radiological Protection Board

Training Centre
NRPB
Chilton, Didcot
Oxon OX11 0RQ
United Kingdom
Tel: 0235-831600
Fax: 0235-833891

Courses in Radiological Protection

Radiation Management Services, Inc.

Radiation Management Services, Inc.
757 McKay Road, Unit 1
Pickering, Ontario
L1W 3C8
Tel: (905) 428-8060
Fax: (905) 428-8451

RMS offers a Radiation Safety Officer Training Workshop every spring and fall. Although this workshop is primarily intended for radiation safety officers or those responsible for radiation protection in an organization, it provides a good introduction suitable for the occupational physician. It covers industrial sources of radiation, properties of radiation, biological effects of radiation, internal and external dosimetry, detection instrumentation and a range of other subjects.

University of Michigan

Radiological Health Faculty
School of Public Health
The University of Michigan
Ann Arbour, MI 48109-2029
Tel: (313) 764-0523
Fax: (313) 764-9424

Radiation Protection Short Course: This course is an integrated program of basic radiation protection principles leading to Radiological Engineering applications to assess and control radiological hazards. It is a two week course divided into Basic Radiological Health and Radiation Engineering but the parts may be taken separately. The Basic Radiological Health portion covers structure of matter, radioactive processes, interactions of radiation with matter, quantities and units, radiation detection, and radiobiology.

ADDITIONAL READING AND SOFTWARE

General Reading:

Canada: Living with Radiation, 1995
(ISBN 0-660-16036-6 available through local bookstore or by mail from Canada Communications Group-Publishing, Ottawa, Canada K1A 0S9)

Risks Associated with Radiation: General Information, INFO-0577, Atomic Energy Control Board, 1995

Information for General Practitioners

What the general practitioner should know about medical handling of overexposed individuals. IAEA-TECDOC-366, International Atomic Energy Agency, 1986

Health Effects of Radiation

Medical effects of ionizing radiation, Mettler, F.A., et al., W.B. Saunders, Philadelphia, 1995

Effects of atomic radiation: a half-century of studies from Hiroshima and Nagasaki. Schull, W., J. Wiley and Sons, Toronto, 1995

Sources and effects of ionizing radiation, United National Scientific Committee on the Effects of Atomic Radiation , United Nations 1994.

Radionuclide Exposure of the Embryo/Fetus, National Council on Radiation Protection, NCRP Report No.128, 1998

Health Surveillance

Revised Guidelines for the Medical Surveillance of Radiation Workers, GMA-8, Group of Medical Advisers, Atomic Energy Control Board, 1993

The Management of Workers Occupationally Exposed to Ionizing Radiation, ACRP-15, Advisory Committee on Radiological Protection, Atomic Energy Control Board, 1993

Health Effects and Medical Surveillance (1998). Practical Radiation Technical Manual. International Atomic Energy Agency IAEA-PRTM-3

Health Surveillance of Persons Occupationally Exposed to Ionizing Radiation:Guidance for Occupational Physicians (1998) Safety Report Series No.5, International Atomic Energy Agency

Radiation Protection

Radionuclide and Radiation Protection Data Handbook, Radiation Protection Dosimetry, Volume 72, No.1-2, 1998

General principles for the radiation protection of workers, ICRP 75, International Commission on Radiological Protection, Pergamon Press, 1997

Individual monitoring for intake of radionuclides by workers: design and interpretation, ICRP 54, International Commission on Radiological Protection, Pergamon Press, 1988

Radiological protection of the worker in medicine and dentistry, ICRP 57, International Commission on Radiological Protection, Pergamon Press, 1989

1990 Recommendations of the International Commission on Radiation Protection, ICRP 60, International Commission on Radiological Protection, Pergamon Press, 1991

Annual limits of intake of radionuclides based on 1990 recommendations, ICRP 61, International Commission on Radiological Protection, Pergamon Press, 1991

Report on External Occupational Dosimetry. ACRP-17, Advisory Committee on Radiological Protection, Atomic Energy Control Board, INFO-0621, 1995

Health Canada, Occupational Radiation Exposures in Canada-1994, Environmental Health Directorate, 95-EHD-195, Health Protection Branch, 1995

Treatment of External and Internal Contamination

Diagnosis and Treatment of Radiation Injuries, Safety Report Series #2, International Atomic Energy Agency, 1998

Guidebook for the treatment of accidental internal radionuclide contamination of workers, Radiation Protection Dosimetry, Vol. 41, No. 1, 1992

Assessment and treatment of external and internal radionuclide contamination. IAEA-TECDOC-870, International Atomic Energy Agency, 1996

Management of persons accidentally contaminated with radionuclides, NCRP 65, National Council on Radiation Protection and Measurements, 1980

Hospital emergency department management of radiation accidents, Robert C. Ricks, Oak Ridge Associated Universities, Office of Development Resources, P.O. Box 117, Oak Ridge TN 37831-0117

Guidelines on the Medical Management of Tritiated Water Overexposure, GMA-7, Group of Medical Advisers, Atomic Energy Control Board, 1995

Guidelines for Counselling after Occupational Overexposure to Ionizing Radiation, GMA-6, Group of Medical Advisers, Atomic Energy Control Board, 1993

Bioassay information

Health and Welfare Canada, Bioassay Guideline 1: General guidelines for bioassay programs, Report of the Working Group on bioassay and *in-vivo* monitoring criteria, Environmental Health Directorate, 81-EHD-56, Health Protection Branch, 1981

Health and Welfare Canada, Bioassay Guideline 2: Guidelines for tritium bioassay, Report of the Working Group on bioassay and *in-vivo* monitoring criteria, Environmental Health Directorate, 83-EHD-87, Health Protection Branch, 1987

Health and Welfare Canada, Bioassay Guideline 3: Guidelines for radioiodine bioassay, Report of the Working Group on bioassay and *in-vivo* monitoring criteria, Environmental Health Directorate, Health Protection Branch, 85-EHD-95, 1985

Health and Welfare Canada, Bioassay Guideline 4: Guidelines for uranium bioassay, Report of the Working Group on bioassay and *in-vivo* monitoring criteria, Environmental Health Directorate, 88-EHD-139, Health Protection Branch, 1988

Information on Specific Radioisotopes

Radioisotope Safety: Iodine -131, INFO-0546-1, Atomic Energy Control Board

Radioisotope Safety: Iodine-125, INFO-0546-2, Atomic Energy Control Board

Radioisotope Safety: Phosphorus-32, INFO-0546-3, Atomic Energy Control Board

Management of C-14 in Canadian Nuclear Facilities. ACRP-14, Advisory Committee on Radiological Protection, Atomic Energy Control Board, INFO-0569, 1995

GMA-7, Guidelines on the Medical Management of Tritiated Water Overexposures, Group of Medical Advisers, Atomic Energy Control Board, September 1995 (AECB INFO-0586).

Probability of Causation

Methods for estimating the probability of cancer from occupational radiation exposure. IAEA-TECDOC-869, International Atomic Energy Agency, 1996

The probability that a particular malignancy may have been caused by a specified irradiation. NCRP Statement No.7, Issued September 30, National Council on Radiation Protection and Measurements, 1992

Death of a classified worker probably caused by overexposure to ã radiation. D.C. Lloyd et al., Occupational and Environmental Medicine 51: 713-718, 1994

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Probability of causation: Implications for radiation protection. R. Vetter, Health Physics, 64(2):115, 1993

Legal Aspects

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Summary of experience in radiation litigation. V. Collins. in CRC Handbook of Management of Radiation Protection Programs, eds. K.L. Miller et al., 2nd ed., CRC Press, 1992

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The medical and scientific basis for legal liability related to radiation exposure. V. Collins, in CRC Handbook of Management of Radiation Protection Programs, eds. K.L. Miller et al., 2nd ed., 1992

Radiation litigation update: Whiting v. Boston Edison Co., An important legal development in controlling expert testimony based on "junk science". Wiedis, D. et al., Radiation Protection Management, 13(1):57-66, 1996

ALARA: Two court decisions with dramatically different implications. Wiedis, D. and Jose, D., Nuclear News, June 1996

Software

ASQRAD: Assessment system for the quantification of radiation detriment software. Publication of the European Commission EUR 16644 EN, 1996 (available from: Centre d'étude sur l'evaluation de la protection dans le domaine nucléaire, Route du Panorama BP 48 F-92263 Fontenay aux Roses Cedex).

This is a Windows based PC tool for the quantification of detriment from somatic and hereditary effects for populations and individuals. It contains a data base from several countries but allows the user to input alternate data and parameters.

SURVRAD: This Windows based PC tool is designed to estimate lifetime risks of radiation induced cancer. It was designed to project radiation risks for populations but can perform probability of causation calculations for specific age at diagnosis or death.

It is available from Viking Software Corporation, P.O. Box 890245, Houston, Texas 77289-0245 Tel: (713) 488-9025; FAX: (713) 488-9025

Ludep 1.0: Personal computer program for calculating internal doses using the new ICRP respiratory tract model. Jarvis, N.S. et al., National Radiological Protection Board SR264, 1993 It is available from NRPB, Publications Office, Chilton , Didcot, Oxon OX11 ORQ, United Kingdom.

USEFUL WEBSITES

http://www.sph.umich.edu/group/eih/UMSCHPS
This us an excellent all-purpose, one stop site developed by the University of Michigan's Student Chapter of the Health Physics Society. It contains a wealth of information and links related to radiation and radiological health that is suitable for the general public, students and health physicists. It also has a list of hot-lines.

http://radefx.bcm.tmc.edu/ionizing
Baylor College of Medicine has created this site of radiation health effects research including disaster preparedness; health effects of nuclear weapons used on the cities of Hiroshima and Nagasaki; agencies, commissions, departments, institutes and organizations; research and selected publications.

http://www.dne.bnl.gov/CoN/index.html
This has complete information on all known nuclides.

wysiwyg:cnf.68/http://www.ncf.carleton.ca/~cz725/cnf.htm
A physicist from AECL is the author of this unofficial and privately maintained website. It contains a list of Frequently asked questions regarding nuclear power generation in Canada and currently spans 38 pages.

http://www.nrc.gov/NRC/NUREGS/BR0217/br0217.html#_1_10
US Nuclear Regulatory Commission is responsible for this site which has useful information on radioisotopes and their uses.

http://www.cannon.net/~gonyeau/nuclear/frmain01.htm
This site is called the "virtual tourist" and it provides information on the design, construction and operation of nuclear power plants around the world.

http://www.hc-sc.gc.ca/ehp/ehd/rpb
This is the Radiation Protection Bureau of Health Canada.

http://www.iaea.or.at/worldatom/
This is the International Atomic Energy Agency's public information Internet service.

http://www.irpa.at/
The International Radiation Protection Association.

http://www.tue.nl/sbd/irpa/icrp.htm
The International Commission on Radiological Protection.

http://cedr.lbl.gov/
This is a comprehensive epidemiological data resource (CEDR) on the studies of radiation health effects developed by the Department of Energy.

http://www.ncrp.com/

The National Council on Radiation Protection and Measurements.

http://www.nrpb.org.uk
The National Radiological Protection Board of the United Kingdom.

http://www.orau.gov/ehsd/reacts.htm
Radiation Emergency Assistance Centre/Training Site. Information on their resources which includes training, advice and on site assistance worldwide.

http://www.cdc.gov/
Contains a full text of a number of papers pertaining to the health effects of ionizing radiation.

http://www.cjp.com/radres/html/links.htm#others
This website has numerous links to other sites and databases related to ionizing radiation. Radiation Research is the official journal of the Radiation Research Society.

http://www.afrri.usuhs.mil/
Armed Forces Radiology Research Institute.

http://radnet.jpl.nasa.gov/
This site contains a radiation effects test data for total ionizing dose (TID) and single event effects (SEE).

http://www.aecb-ccea.gc.ca
This is the Atomic Energy Control Board.

http://www.aecl.ca
This is Atomic Energy Canada Limited.

WHAT SHOULD I KNOW ABOUT TREATMENT OF INTERNAL CONTAMINATION WITH RADIONUCLIDES?

Reduction of internally deposited radionuclides can be accomplished by means of two general processes: (1) reduction of absorption and internal uptake, and (2) enhanced elimination or excretion of absorbed radionuclides. Both are achieved more effectively when treatment is begun at the earliest time after exposure.

Skin decontamination and wound management are used to reduce uptake via the skin.

Reduction of Gastrointestinal Absorption
Blocking and Diluting Agents
Mobilizing Agents
Chelating Agents
Lung Lavage
Hemodialysis
Treatment Summary of Selected Internal Radioactive Contaminants

REDUCTION OF GASTROINTESTINAL ABSORPTION

Gastrointestinal absortion can be reduced either by removing radioactive materials before absorption can occur or by blocking uptake by use of drugs.

1. **Stomach lavage**. A nasogastric or gastric tube may be used to empty the stomach in the unusual circumstance where a large quantity of radionuclide is present in the stomach. The addition of charcoal may also retard ingestion.

2. **Emetics.** Stomach lavage is often the procedure of choice, but may not always be successful. Apomorphine hydrochloride or ipecac are the most likely emetic drugs to consider in such cases.

3. **Purgatives**. Selection of purgative to speed the elimination of gastrointestinal tract contents depends largely on the speed of action. An exposure of concern would be relatively insoluble radionuclides that may remain for many hours in the colon and rectum, and could be removed promptly with treatment. A phosphosoda enema will empty the colon in a few minutes and should be a primary consideration. Purgative drugs taken orally, such as biscodyl, castor oil, or phenolphthalein, require several hours before taking effect, but they have faster action than others. Some purgatives may have special advantages because they produce a less soluble compound of certain radionuclides. Magnesium sulfate is a saline cathartic that can produce relatively insoluble sulfates with some radionuclides, e.g., radium.

4. **Ion exchange resins**. Strong cation or anion exchange resins can produce toxic side effects and are generally not recommended. While no studies are noted in the literature on the use of activated charcoal in cases of radionuclide intake, it would seem to be a potentially useful procedure to reduce uptake.

5. **Prussian Blue**. In animals, ferric ferrocyanide (Prussian Blue) has been found effective in accelerating the removal of cesium, thallium and rubidium through feces. Prussian Blue is not absorbed from the gastrointestinal tract and has low toxicity. One to three grams of Prussian Blue given 3 times per day from several days up to 3 weeks is well tolerated in adults. In man, the compound has reduced the biological half-time of Cs-137 to one third of the normal value.

6. **Aluminum-containing antacids**. These are effective agents in reducing intestinal uptake of strontium. A single oral dose of 100 ml aluminum phosphate gel given immediately after ingestion of radioactive strontium will decrease absorption by about 85%. A single dose of aluminum hydroxide, 60 to 100 ml, given immediately after exposure will reduce uptake by about 50%. Both drugs are nontoxic and well tolerated.

7. **Barium sulfate**. This highly insoluble salt is used as an x-ray contrast agent for gastrointestinal tract examinations. Except for constipation, no adverse effects have been observed. In an emergency response to a radionuclide ingestion, the principal indication for use of barium sulfate is as an immediate antidote for ingested strontium and radium. Formation of insoluble sulfates of these elements will decrease their intestinal absorption.

BLOCKING AND DILUTING AGENTS

A blocking agent saturates a specific tissue with a selected stable element and thereby reduced the uptake of a radionuclide usually taken up by that tissue. Isotopic dilution is achieved by the administration of large quantities of a selected stable element (compound), which lessens the organ uptake of radionuclide due to the dilution factor. Displacement therapy is a special form of isotopic dilution in which a stable element of a different atomic number successfully competes with the radionuclide for uptake in an organ. Some of the more practical examples of these agents are summarized.

1. Iodides

The early use of stable iodide can reduce uptake of radioiodine in the thyroid. A dose of 390 mg of potassium iodide (300 mg iodide) achieves maximal blocking. Administration of a single dose of stable iodide within the first few minutes after exposure to radioiodine may limit uptake of about 1 or 2% compared with the normal 12 to 20% uptake. Only about half of the uptake is blocked if the iodide administration is delayed 6 h and little effect can be achieved if delayed as much as 12 h. Daily administration of potassium iodide (KI) is recommended for about 7 to 14 d to prevent recycling of the radioiodine into the thyroid. The above dose schedule is recommended for individual exposures, but for general public use in emergencies a lower dose of 130 mg KI (100 mg iodide) has been recommended. Reported adverse reactions from daily 300 mg doses of iodide suggest a reaction rate of about 1 to 10/10,000,000 [Lu80]. Incidence of adverse reactions are related to dose and length of administration. After iodine administration given usually for several weeks or longer, the reported iodine-induced reactions include thyrotoxicosis, iodide goiter, hypothyroidism with goiter, iodide parotitis, acneform skin eruptions, and even less frequent systemic manifestations (fever, arthralgia, inflammatory joint involvement, etc.). Because these reactions reverse in a few days after discontinuing the drug, monitoring for reactions need not be continued beyond a few days after the last iodide administration. The side-effects problem is thought to be very small for the dose schedules discussed here.

2. Strontium

Stable strontium is useful as a diluting agent for radiostrontium. It is available as tablets (strontium lactate, 300 mg, to be given 2 to 5 times daily) or intravenous solutions (strontium gluconate, 600 mg strontium per day infused with 500 ml 5% glucose in water over 4 h). The tablets are well tolerated if given with meals and are nontoxic at this dosage. It can be given daily for several weeks.

3. Phosphate

Phosphate can be used to decrease the intestinal absorption of radioactive strontium. It may also be useful as a diluting agent in case of medical misadministration of P-32. Oral phosphates can be given in inorganic (sodium or potassium phosphate) and organic forms (sodium glycerophosphate). Vomiting, diarrhea, or both may occur from phosphate administration in doses exceeding 2 g/d. Phosphate can be used as a saline cathartic. Intravenous administration of phosphate is unlikely for treatment of radionuclide uptake. It must be done cautiously because rapid administration can cause

severe hypotension, renal failure, and myocardial infarction. Serum calcium and electrocardiograms must be monitored during such infusion.

4. Forced Fluids

A high level of fluid intake by mouth will increase tritium excretion proportionately. The biological half-life of tritium in the body can be reduced by forcing at least 3 to 4 litres of fluid per day. Continue forcing to tolerance for at least 1 week or until further dose reduction is judged not to be necessary. The dose may be reduced by a factor of 2 or more by careful management.

5. Calcium

Orally and intravenously administered calcium increases the urinary excretion of radioactive strontium and calcium.

MOBILIZING AGENTS

Mobilizing agents are compounds that increase a natural turnover process, thereby inducing a release of some forms of radioisotopes from body tissues. This results in an enhanced rate of elimination from the body and a reduced biological half-time. These agents are more effective given soon after exposure, but some still produce an effect if given within about 2 weeks.

1. Antithyroid Drugs

The treatment of choice for reducing the dose from radioactive iodine is to block the thyroid by administration of stable iodine. If the time since exposure is 12 h or more, the use of stable iodine has limited effectiveness because the radioactive iodine is already deposited in the thyroid. In this situation the use of an antithyroid drug, such as propylthiouracil or methimazole, may be considered. These drugs interfere with the oxidation of the iodide ion and block the formation of hormone. The response to these drugs is greatly reduced if the thyroid already has an ample supply of stable iodine, such as when stable iodide has already been administered. The risk of side effects is much higher than with stable iodine. About 2 to 8% of patients on these drugs develop a maculopapular rash, which does not usually require discontinuation of the drug. Much rarer but serous side effects are hepatocellular damage, vasculitis, and agranulocytosis (in about 0.2% of patients). These side effects are usually reversible on discontinuance of the drug. The effective half-time of I-131 was reduced about 25% using methimazole in several human volunteers when given several days after radioiodine administration [Ha86]; thus, the reduction of radiation dose is not likely to be great if treatment is started as late as several days after exposure.

2. Ammonium Chloride

This acidifying salt given orally (1 to 2 g four times a day) is effective in mobilizing radioactive strontium deposited in the body. Its effectiveness can be enhanced by simultaneous use of i.v. calcium gluconate, 500 mg calcium in 500 ml 5% glucose in water over 4 h on 3 to 6 consecutive days. An estimated reduction in the body burden of radioactive strontium between 40 to 75% may be obtained if started soon after exposure. Ammonium chloride frequently causes gastric irritation, nausea, and vomiting, and should not be used in persons with serious liver disease.

3. Diuretics

The value of diuretics is untested for treatment of internal radionuclide deposition. Enhanced excretion of sodium, chloride, potassium bicarbonate, magnesium, and water in the urine occurs with induced diuresis.

4. Expectorants and Inhalants

Studies on the effects of these agents on inhaled radioactive particles are disappointing. None provides effective action that would be dependable or particularly useful in treating persons after inhalation of radioactive particles.

5. Parathyroid Extract

Injections of parathyroid hormone promote urinary excretion of phosphorus have been used effectively to treat an overdose of radioactive phosphorus.

CHELATING AGENTS

A number of chemical compounds enhance the elimination of metals from the body by chelation, a process by which organic compounds exchange less firmly bonded ions for other inorganic ions to form a relatively stable nonionized ring complex. This soluble complex is excreted readily by the kidney. The excretion of certain radionuclides can be increased by means of a properly selected and administered chelating agent. Chelation therapy is most effective when it is begun as soon as possible after exposure because it works only on the metallic ions in extracellular fluids and not on those already incorporated in cells.

The principal drug used for treatment of radionuclides is known as DTPA, an acronym of its chemical name, diethylenetriaminepentaacetic acid. It is useful for the chelation of plutonium, berkelium, californium, americium, and curium. In addition to these trans-uranium metals (atomic numbers greater than that of uranium), DTPA is also an effective chelator for some rare earths (elements with atomic numbers between 58 and 71: cerium, yttrium, lanthanum, promethium, and scandium) and some transition metals (zirconium and niobium).

Animal studies indicate that the ZnDTPA form is less toxic than CaDTPA in some situations. ZnDTPA is recommended for long-term treatment and for use in pregnant women. CaDTPA is more effective than ZnDTPA in rats when it is given promptly after exposure to transuranium metals. For this reason, CaDTPA is the preferred form to use during the first day or two of treatment.

No serious toxicity has resulted in man with either ZnDTPA or CaDTPA when used in recommended doses. In high doses in animals, toxicity has occurred from CaDTPA due to chelation and excretion of trace metals, such as zinc and manganese. Doses in animals at levels 200 times or more than used in humans produce severe lesions of the kidneys, intestinal mucosa, and liver in animals. Teratogenesis and fetal death occur in mice when similarly high doses are given throughout gestation.

For plutonium exposures, the effectiveness of DTPA chelation is highly dependent on the chemical form of the plutonium. Soluble forms, such as the nitrate, are taken up into extracellular fluids quickly where chelation can take place. Data from persons treated with CaDTPA within about 3 h of exposure indicate that about 60 to 70% of soluble plutonium is removed compared to untreated persons. This is true for both inhalation and contaminated wounds. Insoluble plutonium forms, such as high-fired oxides, are absorbed into the extra-cellular fluids slowly over many months. In this case the plutonium concentration in extra-cellular fluid is minute and chelation does not enhance excretion significantly.

The recommended dose for either ZnDTPA or CaDTPA is a single 1 g dose per day. The dose should not be fractionated, i.e., given in multiple doses per day. It can be given either intravenously or by aerosol inhalation. The usual procedure for i.v. administration has been to dilute 1 g DTPA in 250 ml normal saline or 5% glucose in water and given over a period of about 30 min. An alternate procedure, using 1 g diluted in 10 or 20 ml normal saline and injected i.v. over a period of five min is preferred by some physicians. In either case, care should be taken to avoid extravasation from the vein. Aerosol administration is done with 1 g CaDTPA placed in a nebulizer and the content inhaled over 15 to 20 min. ZnDTPA is less well suited than CaDTPA for aerosol administration because of its metallic taste. It is prudent not to use the inhalation route in persons with pre-existing pulmonary disease.

Clinical urinalysis should be performed and be normal prior to each treatment. Potential contraindications to use of the drug are significant leukopenia, thrombocytopenia, or serious kidney dysfunction.

DTPA is not commercially available in Canada but can be imported from Germany under certain conditions with approval from Health Canada by following a specified procedure. It should be noted that the procedure for obtaining approval can be lengthy. There is a supply of DTPA at the Toronto Hospital, Radiation Trauma Unit available for emergency use. There is also a supply of DTPA at the Atomic Energy Canada Limited, Chalk River Laboratories. This is supplied through the U.S. Radiation Emergency Assistance Centre and Training Site through a co-investigator network of physicians. In the U.S., DTPA has received approval for investigational use by the Food and Drug Administration.

LUNG LAVAGE

Inhalation of radioactive particles is a common mode of intake from occupational exposures. If the particles are insoluble, a large proportion of the radioactive material is retained for many months or years in the lung. Chelation therapy is not effective in these cases.

In dog studies, lavage of the tracheobronchial tree removes about 25 to 50% of inhaled insoluble particles [Bo53, Th59, He52]. The procedure requires placement of an endotracheal tube into the trachea and major bronchi under a general anaesthesia. The airways are lavaged with isotonic saline. Experimentally, five lavages were performed on both right and left lung, ten total, starting in the first week after exposure and doing one lavage from three days to a week apart. Radiation pneumonitis and early deaths occurred in only 25% of treated dogs in contrast to death of all untreated dogs. In baboons, 60 to 90% of the lung burdens of plutonium oxide was removed by ten pulmonary lavages [Sh61].

Use of this treatment requires a careful risk-benefit assessment. The risk lies primarily in the administration of a general anaesthetic. The mortality risk appears to be 0.2% or higher for each lavage. This procedure risk is immediate, whereas radiation-induced cancer risk to the lung will be years later. The use of this procedure should, therefore, be limited to cases in which lung doses from insoluble particles of alpha emitters are sufficiently high to produce acute radiation damage.

HEMODIALYSIS

Blood dialysis may have limited advantages in removing remaining radioactive cesium. By 4 hours 90% of the administered activity can be removed [Ve95].

Hemodialysis also has a potential application for the treatment of tritiated water overexposures [GM95].

TREATMENT SUMMARY OF SELECTED INTERNAL RADIOACTIVE CONTAMINANTS

Contaminant	Procedure	Medication	Comment
Americium	Wound excision	DTPA*	See Transuranic elements
Californium	Wound excision	DTPA*	See Transuranic elements
Cerium		DTPA*	See Rare earths
Cesium		Prussian Blue*	
Curium	Wound excision	DTPA*	See Transuranic elements
Hydrogens (tritium)		Water	Force fluids to tolerance
Insoluble Particles			
Ingested	Stomach lavage		
Inhaled	Lung lavage		
Iodine		Purgatives KI or NaI	If acute effects expected
Lanthanum		DTPA*	See Rare earths
Mercury		Penicillamine	
Phosphorus		Phosphates	Aluminum-containing antacid for ingestion
Plutonium	Wound excision	DTPA*	See Transuranic elements
Rare earths (atomic numbers between 58 and 71)		DTPA*	
Strontium		Strontium/Calcium Oral ammonium chloride	Aluminum-containing antacid for ingestion 1 g/d i.v. or by aerosol
Transuranic elements (Atomic number greater than uranium)		DTPA*	
Zinc		CaDTPA*	

* Health Canada approval needed for this use

DOCUMENTS BY THE GROUP OF MEDICAL ADVISERS

GMA-1	(superceded by GMA-8)
GMA-2	Guidelines on Radiation Exposure Levels for Emergency Situations (1992)
GMA-3	Guidelines on Hospital Emergency Plans for the Management of Minor Radiation Accidents (1992)
GMA-4	Guidelines on the Management of Patients Treated with I-131 (1993)
GMA-5	Guidelines for Research in Human Subjects Using Ionizing Radiation (1994)
GMA-6	Guidelines on Counselling After Occupational Overexposure to Ionizing Radiation (1993)
GMA-7	Guidelines on the Medical Management of Tritiated Water Overexposures (1995)
GMA-8	Revised Guidelines for the Medical Surveillance of Radiation Workers (1993)
GMA-9	Guidelines on the Use of Stable Iodine as a Prophylactic Measure During Nuclear Emergencies (1996)
GMA-10	The Observed and Predicated Health Effects of the Chernobyl Accident (1996)
GMA-11	(to be published as a joint working group document AC-9 Principles of the Management of Radionuclide Therapies - expected by 2000)
GMA-12	Guide to Ionizing Radiation Exposure for the Occupational Physician (1999)
GMA-13	Review of Quality Assurance in Radiation Therapy (1998)
GMA-14	Guidelines for Community Hospitals in the Handling of Radiation Accident Patients (expected late 1999)

WHAT ARE COMMONLY ASKED QUESTIONS?

Questions and answers are taken from "Risks Associated with Radiation: General Information", published by the Atomic Energy Control Board (INFO-0577)*:

What is radiation?

Radiation is a form of energy, either in the form of electromagnetic rays or subatomic particles. There are several different types of radiation, which have widely differing properties (i.e. ionizing and non-ionizing radiation). The types of radiation considered in this document are of the ionizing type encountered in the nuclear industry, such as gamma rays, beta particles, neutrons and alpha particles. Non-ionizing radiation, such as microwaves and ultra-sound, will not be considered since they are not related to the use of nuclear energy. It is the ionization property that gives rise to the health effects that will be discussed.

What is ionizing radiation?

Ionizing radiation is radiation of high enough energy to create charged particles called ions in the materials in which it is absorbed. In human tissues, these charged particles can result in damage to individual cells and give rise to certain effects. (See question 6 for further details.)

How does ionizing radiation occur?

It occurs as an outcome of the natural decay of radioactive substances, the breakup (fission) of certain radioactive materials, or it can be produced by X-ray machines and particle accelerators. Examples of such radioactive materials are uranium in rock formations, radionuclides used in a hospital, and the fuel in the core of a nuclear reactor.

What are the sources of natural background radiation exposure of an individual?

Cosmic radiation from outer space is a major component of natural radiation, and many rocks and building materials contain traces of radioactive materials that give off ionizing radiation. Another important source of natural radiation is radon, a gas that forms from the decay of uranium. Radon may enter buildings from the soil and reach significant concentrations in confined spaces such as

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* These questions and answers are directed towards activities licensed by the Atomic Energy Control Board and therefore x-rays which are similar to gamma rays are not specifically discussed in this section, but the information is generally applicable. These questions and answers have been slightly modified from the original text to allow them to stand alone in this document.

basements, depending on the radium content of the surrounding soil and a number of other factors. When inhaled, radon, and its radioactive decay products, deliver a dose of radiation to the lung tissues. In addition to these sources, the human body contains uranium and thorium from dietary sources. Potassium, a constituent of our bodies, is naturally radioactive to a small degree due to its isotope potassium-40.

What are the levels of natural background radiation?

The total dose to individuals received in a year from natural radiation varies from 2 to 4 millisieverts (mSv) in Canada. For individuals in elevated locations, the cosmic ray dose is higher than at sea level. Similarly, in areas where the rock or soil has a high uranium or thorium content, the radiation dose is higher than average. Radon concentrations in buildings also vary markedly with the type of underlying rock and the type of construction.

How does radiation affect the body?

If radiation strikes the body, each ray or particle of radiation may set off a series of physical and chemical events, starting with ionization, which can result in damage at a molecular or cellular level. For instance, the nucleus of a cell can be damaged or the cell may be killed. A damaged cell may reproduce and thus multiply the damage. In some cases, the cell is able to repair the damage. It is important to realize that this process is going on all the time in everyone. In fact, we are all subjected to about 15,000 such events every second of our lives from natural sources of radiation. Sometimes, a faulty repair occurs and may alter the cell structure. These alterations may remain without further effect or may lead to effects that show up later.

What sort of effects are we talking about?

a) Stochastic effects: Cancer and hereditary effects are considered as "stochastic" effects. The word "stochastic" refers to the probability or chance of the effect taking place. In other words, the effect may or may not take place. However, it is assumed that the possibility is always there, no matter how low the radiation dose, and that the probability of there being an effect increases as the dose gets larger. This assumption of there being no dose level or "threshold" below which the probability of an effect is zero, and of the probability increasing proportionally with the amount of dose, is called the "linear, non-threshold assumption". It should be noted that for stochastic effects, it is the probability of having an effect rather than the severity of the effect that increases with the amount of dose.

At a dose of 10 mSv, the effect on an individual is a slight increase in the chance of cancer occurring over a lifetime (500 additional fatal cancers would be expected per one million exposed individuals). This increase is very small when compared to the risk of dying of cancer from other causes (the normal percentage of deaths from cancer in Canada is about 27 per cent or 270,000 in a million individuals over a lifetime). It should be noted that cancers caused by radiation are of the same types as those due to other causes, and hence are indistinguishable from them. Canadian cancer statistics show that all of us have about a 1 in 4 chance that our eventual death will be due to cancer. This overall rate has stayed fairly constant for a number of years, although the frequencies of different types of cancer may vary.

The occurrence of genetic effects in the children of persons exposed to radiation is also subject to chance. This means that children of the individuals receiving the radiation may or may not experience the effects. The type of genetic effects (e.g., gene mutations and chromosome abnormalities) are the same as those experienced from other causes. It should be noted that the genetic effects have not been observed in humans. Therefore, the animal studies provide the basis of information for this type of effect.

b) Non-stochastic effects: In contrast to stochastic effects, the severity of "non-stochastic" or "deterministic" effects depends on the amount of dose received. The probability of causing harm will be zero up to some level of dose called "threshold". These effects include cataracts, non-malignant skin damage (radiation burns), blood deficiencies, and reduced fertility, which can only occur when the radiation dose is above a certain level. The regulatory permissible limits are designed to keep the radiation dose well below this threshold, in which case the risk is zero for this type of effect.

How do risks vary with radiation dose?

Most of the information on stochastic effects of radiation has been obtained from animal studies, and from studies of the atomic bomb survivors in Japan and of humans exposed to high doses during medical treatment. The risk estimates for low doses, such as these normally received in radiation work, therefore have to be derived from the information obtained at much higher doses.

However, there is good evidence that at the very low doses received by radiation workers, the stochastic effect per unit of dose is lower than that seen at high doses, and the risk estimates have been modified to reflect this difference.

Nevertheless, it is prudently assumed that in the low-dose range, the chance of a stochastic effect increases in direct proportion to the dose. This assumption is fundamental to radiation protection and has a very important consequence: however low the dose is, some small chance of an effect remains. It follows that no threshold is assumed for stochastic effects.

In practice, for annual doses below the regulatory limits, the chance of stochastic effects is so low, compared to the rate at which these effects occur due to other causes, that they cannot be distinguished statistically, even in relatively large groups of people. At these low levels, natural statistical variations in the effects (cancer, genetic effects) are large enough to obscure any effects caused by radiation.

Therefore, obtaining conclusive evidence for or against this assumption of "no threshold" is difficult. Arguments in favour of a threshold are that the body has efficient repair mechanisms that are constantly repairing cells from many types of damage, including natural background radiation. Also, many substances that are toxic at high doses can be tolerated with no or minimal effects at low doses. On the other hand, the beginning of cancer, because it is thought to be caused by damage in cells, and in particular in the "information store" of the cell nucleus, may appear to be a process without a threshold. There is a chance that a single radiation ionization event could produce a defect in the cell nucleus that could eventually lead to cancer, particularly if the cell has already been damaged by other agents such as chemicals or viruses. A single ionization event could be caused by an extremely low dose, and thus effects could theoretically result from

extremely low doses. To put this one event in perspective, however, it should be noted that our bodies are subjected to 15,000 such events every second from natural background radiation.

What doses of radiation are considered harmful?

A dose of several thousand millisieverts delivered in a short period of time over the whole body will kill most humans within a few days. However, this same dose, delivered in small amounts over many years, may have no ill effects at all, because the body is able to repair damage if the damage occurs slowly. The word "may" is emphasized because certain radiation effects have a finite probability of occurring, even at low doses. These are called "stochastic" effects. The only known stochastic effects to arise from exposure to radiation are cancer in the individual and hereditary disorders in the offspring. This means that an increasing dose of radiation increases the probability that a cancer will occur. If a cancer does in fact occur, the severity of the cancer is not influenced by the size of the dose, and the cancer behaves like any other cancer.

What are the actual doses experienced by Canadian radiation workers?

Annual reports of the National Dose Registry, which is administered by Health Canada, indicate that the overall annual average dose for Canada's 120,000 radiation workers (including those exposed to X-rays) is about 0.33 mSv from occupational exposure. For two of the categories of workers, namely industrial radiographers and fuel handlers, the average annual doses vary from 2 to 5 mSv, respectively.

What are the principles of radiation protection?

Exposure to radiation and the resulting doses are controlled by applying a system that is based on the following principles:

a) Justification: no use of radiation or radioactive materials should be adopted unless it introduces a positive net benefit to society;

b) Optimization: all radiation exposures should be kept As Low As Reasonably Achievable, economic and social factors being taken into account (usually referred to as the ALARA principle); and

c) Dose limitation: the radiation dose to individuals must not exceed the regulatory limits appropriate for the circumstances.

These principles have been developed by the International Commission on Radiological Protection (ICRP), a body of international experts supported by governments, that examines the scientific evidence available and makes recommendations on radiation protection. These recommendations have been followed closely by the AECB in establishing the Canadian regulatory process and dose limits. The ICRP approach is also endorsed and used in most other countries and by international organizations, such as the World Health Organization, International Labour Organization, the International Atomic Energy Agency and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD).

How is the dose limitation system applied?

Dose limits for individuals from nuclear activities are incorporated in regulations made under the Atomic Energy Control (AEC) Act. All persons who are responsible for the operation of a nuclear facility or the possession or use of radioactive materials must be licensed under these regulations, and must ensure that no one receives a dose of radiation in excess of these limits as a result of their activities. In the future, dose limits will become incorporated in regulations which are being made under the Nuclear Safety and Control Act.

The AECB is the regulatory authority which administers the AEC Act, issues the licences and enforces the regulatory requirements. Those applying for licences must indicate how they intend to prevent individuals from exceeding the dose limits. They must also identify the conditions under which they intend to operate their facility or use the radioactive material, describe the measures for limiting radiation doses, estimate the associated doses to the workers and the public, and provide sufficient evidence that these doses will be at an appropriately low level, in line with the ALARA principle. The appropriate conditions are then included in the licence.

What are the current limits for radiation workers?

At the present time, the basic occupational dose limit is 50 mSv per year. However, the ICRP is now recommending a further limit of 100 mSv over five years, based on revised estimates of radiation risk. The new estimates come mainly from more detailed analysis of the data from studies of the atomic bomb survivors. The new recommendations of ICRP (1990) maintain the limit of 50 mSv in any single year, but introduce a five-year averaging process to limit doses to an average of 20 mSv per year. This has the effect of restricting doses approaching 50 mSv per year to exceptional circumstances. The AECB is in the process of incorporating these recommendations into regulations under the Nuclear Safety and Control Act.

What level of health risk is associated with the current dose limits in the AEC Regulations?

As pointed out earlier, the only reliable data that exist on the effects on humans come from high doses, such as those experienced by atomic bomb survivors and patients given high doses of radiation for medical purposes. Assuming that the effects at lower doses will be proportional to the ones observed at high doses, the ICRP has estimated the probabilities of fatal cancer from the low levels of radiation received in the workplace. The chance of fatal cancer to individuals, used by the ICRP up until 1990, was about 13 per million per mSv of whole body exposure. The ICRP had decided prior to 1990 that risks from working with radiation must be no greater than the risk generally accepted by workers in safe industries. The ICRP noted that workers in safe industries appear to be willing to accept work-related fatalities of 100 per one million workers per year. This risk factor leads to an annual dose limit of about 5 mSv. However, the ICRP had also suggested that annual average occupational doses were generally one-tenth of 50 mSv and consequently recommended that 50 mSv per year be used as a limit in conjunction with rigorous application of ALARA.

According to the new ICRP recommendations (1990) mentioned in the answer to question 13, the chance of fatal cancer to workers from the low level of radiation received at a workplace is now estimated to be about 40* per million per mSv whole body exposure. The ICRP decided to

bring out its new recommendations after observing an increase in the estimated probability of cancer risk for low-dose and low-dose rate irradiation based on the new evidence from epidemiological data from atomic bomb survivors.

Are the radiation risks different for men and women?

The incidence of thyroid and breast cancer caused by radiation is higher in women than men, while for leukaemia the reverse is true. The overall difference is not enough to make separate dose limits necessary.

However, major differences are found in the case of a fetus, since the fetus is, in general, more sensitive to radiation than the adult man or woman. This therefore leads to different dose limits for women who are pregnant.

What are the effects on the fetus?

Radiation exposure may cause birth defects, mental retardation, decrease in IQ, hereditary defects that can be passed on, childhood cancer and cancer in adult life. At the current limit of 10 mSv during the remainder of the pregnancy following disclosure, the first three effects are considered to be non-existent. The last three effects however do have a small chance of occurring at doses of 10 mSv, the probability being about 2000 in a million. Most of that risk comes from the possibility of cancer later in adult life, and that figure is not accurately known. The only estimate is based on the bomb survivors who were in the womb at the time. Since they are now about 50 years old, they are only just entering the period of increasing natural cancer incidence, and so it will be some years before it will be known how much their cancer rate is elevated, if at all. The ICRP (1990) has recommended new dose limit for the pregnant worker rather than the fetus, for the practical reason that it is in many cases impossible to measure or even calculate the dose to the fetus. The new limit is much lower than the current one. The ICRP recommended that doses to the surface of the abdomen of pregnant workers be limited to 2 mSv and the intake of radionuclides be limited to 0.05 ALI (Annual Limit on Intake) during the pregnancy.

Is there anything the worker can do to reduce his or her individual risk?

In obtaining a licence to carry out work involving radiation, an employer is required to satisfy the AECB that proper equipment, protective clothing, and procedures are available to keep workers' radiation doses as far below the limit as is reasonably achievable.

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* The ICRP 1990 risk factor for workers is 4×10^2 per Sv (40 fatal cancers per one million per mSv whole body exposure). The corresponding value for the whole population is 5×10^2 per Sv (50 fatal cancers per one million per mSv whole body exposure) which applies to individuals of all ages including children.

By conscientiously using the equipment, protective clothing and procedures provided by the employer for working with radiation, the worker will be making an important contribution to keeping his or her radiation dose and that of fellow workers as low as is reasonably achievable. Since procedures cannot be made explicit enough to cover all situations, the worker should use common sense in dealing with radiation, not take short cuts when following the procedures, and try to recognize unusual situations. Workers should ensure that they know how to handle accidents, and be able to identify when radiation safety experts should be called in.

Although the risks from occupational radiation are low, they are usually additional to other occupational risks. It is sensible to try to keep radiation doses as low as reasonably achievable. This can be done, while still performing one's work properly, by good training, good protective equipment, strict attention to the safety rules, and the use of common sense.

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GLOSSARY OF TERMS

absorbed dose: the mean energy the mean energy of ionizing radiation absorbed by or deposited in a unit of mass of tissue; unit gray (Gy)

activity: the number of nuclear transformations of a radioactive nuclide per unit time; units: becquerel (Bq)

annual limit on intake: the amount of radioactive substance taken into the body in one year that will result in a "committed dose" equal to either the stochastic or deterministic dose limit; different ALI values apply to "intake" by inhalation and ingestion, and different values apply to radiation workers and members of the public

becquerel (Bq): a standard international unit of radioactivity, equal to one radioactive disintegration per second. The obsolete unit curie or Ci, based upon the amount of radioactivity in a gram of radium, equals 3.7×10^{10} Bq

BEIR V: Committee on the Biological Effects of Ionizing Radiations, National Research Council that produced the 1990 report, Health Effects of Exposures to Low Levels of Ionizing Radiation

bioassay: direct measurement on an individual, body fluid or excreta, for the purpose of assessing exposure to internally deposited radionulcides

biological half-life: the time it takes for the body to clear a substance from the body by one half

collective dose: the sum of the individual radiation doses received by a group of persons, expressed in person-sieverts

committed dose: the total dose received from a radioactive substance in the body during 50 years following the intake of this substance in the case of workers and 70 years following the intake in the case of members of the population

curie: a unit of activity equal to 3.7×10^{10} disintegrations per second, and is equal to 37 GBq

cytogenetic analysis: analysis of chromosomal aberrations in the peripheral blood lymphocytes for the purpose of assessing chromosomal damage from radiation exposure and estimating a radiation dose

deterministic effects: effects whose severity is frequently a function of dose and for which doses above some threshold dose is required

detriment: the mathematical expectation of individual or collective harm incurred from exposure to radiation, taking into account the probability of each type of deleterious health effect and the severity of each effect

effective dose: sum of the equivalent doses received by different tissues of the human body each multiplied by the internationally recommended values of "tissue weighting factors" assigned to each respective tissue; the "tissue weighting factor" reflects the probability that a unit dose of radiation to the tissue in question will result in a cancer in the exposed person or a serious genetic disorder in the descendants of the exposed person; the sum of the "tissue weighting factors" for all tissues of the body is 1.0. The tissue weighting factors are essentially relative radiosensitivities. The effective dose is the dose which, if given uniformly to the body, would put you at the same risk as the non-uniform dose that one actually received; unit is the same as that for the equivalent dose - sievert (Sv).

effective half-life: the time it takes for the effect on the body from a radioactive substance to be reduced by one half. This takes into account both the physical decay of the radioactive material and its biological clearance from the body

equivalent dose: It is found that the extent of biological damage depends not only upon the amount of energy absorbed, but also on how the energy is distributed within that unit mass. For the same total amount of energy deposited, those types of radiation which produce a dense track of ionized and excited molecules are most effective at promoting biological changes than those types of radiation which produce more widespread distribution of ions. The "equivalent dose" is a quantity that expresses all types of ionizing radiation on a common scale. The "equivalent dose is equal" to the "absorbed dose" multiplied by the appropriate "radiation weighting factor"; unit sievert (Sv)

exposure: exposure to an internal or external source of radiation, or, depending on the context, the product of the concentration of a radioactive substance in air (or the dose rate from a source of radiation) and the duration of exposure to that concentration (or dose rate)

gray (Gy): the special name of the unit of "absorbed dose" (1 Gy = 1 joule/kg); replaces "rad"

high-LET radiation: radiation characteristic of heavy charged particles such as protons and alpha particles where the distance between ionizing events is small on the scale of a cellular nucleus

ionizing radiation: radiation which is sufficiently energetic to dislodge electrons from an atom and thus to produce ions in materials in which it is absorbed

isotope: isotopes are groups of atoms having the same number of protons but varying numbers of neutrons. When radioactive an isotope is called a "**radioisotope**".

LET: linear energy transfer, usually expressed as units of energy deposited per unit length of the track of an ionizing ray or particle

linear model: also, linear dose-effect relationship; expresses the effect (e.g., mutation or cancer) as a direct (linear) function of dose

neutron: an uncharged subatomic particle capable of producing ionizing radiations as an indirect consequence of its collisions with atomic nuclei

non-stochastic effect: see "deterministic effect"

nuclide: are specific isotopes or "nuclear species", e.g., Co-57, Co-59 and Co-60. When radioactive, a nuclide is a "radionuclide".

person-sievert: the unit of population exposure obtained by summing individual "effective dose" values for all people in the exposed population; the unit of "collective dose"

physical half-life: the time it takes for the activity of the radioactive material to be reduced by half due to its physical decay

rad: the special name of the old unit of "absorbed dose"; has been replaced by the "gray"; 1 rad = 10 mGy; 1 Gy = 100 rad

radiation weighting factor: an LET-dependent factor by which absorbed doses are multiplied to obtain (for radiation protection purposes) a quantity (i.e., the "equivalent dose") which corresponds more closely to the degree of biological effect produced by the particular ionizing radiation; "absorbed dose" in Gy x "radiation weighting factor = "equivalent dose"

Reference man: Reference Man, or "Reference Man for radiation protection purposes" is a concept used in estimating the equivalent dose resulting from human exposure to radionuclides. Reference Man is a "typical individual" whose characteristics relating to intake, metabolism, and distribution of radionuclides in the body, are defined precisely. Reference Man is thus the basis for published estimates of radiation dose following specific radionuclide intakes.

relative biological effectiveness (RBE): a term used by radiobiologists. It is the ratio of the absorbed dose of a reference radiation (200 or 250 Kvp of x-rays) to the absorbed dose of a test radiation whcih produces the same level of biological effect.

relative risk: an expression of excess risk relative to the underlying (baseline) risk; if the excess equals the baseline risk, the relative risk is 2.

rem: the special name of the old unit of "dose equivalent" and of "effective dose equivalent"; has been replaced by the "sievert"; 1 rem = 10 mSv.

risk coefficient: the increase in the annual incidence or mortality rate per unit dose: (1) absolute relative risk coefficient is the observed minus the expected number of cases per person year at risk for a unit dose; (2) the relative-risk coefficient is the fractional increase in the baseline incidence or mortality rate for a unit dose.

risk estimate: the number of cases (or deaths) that are projected to occur in a specified exposed population per unit dose for a specified exposure regime and expression period; number of cases per person-sievert.

roentgen or R: obsolete term for measurement of exposure to radiation, sometimes still used in a context such as roentgen per hour. It describes the amount of ionization per unit mass in air.

sievert (Sv): the special name of the unit of "equivalent dose" and of "effective dose" ; replaces the "rem". 1 Sv = 100 rem

stochastic effects: biological effects that may occur at random amongst an exposed group of people, with the probability of occurrence being proportional to the "effective dose", usually without a threshold; cancer and inheritable injury are the stochastic effects of primary concern

threshold dose: the minimum dose below which there is no given biological response or effect

tissue weighting factor: a factor by which the "equivalent dose" received by any organ or tissue of the body is multiplied to calculate an "effective dose" in order to account for the risk of fatal cancer or inheritable injury resulting from irradiation of that organ or tissue compared to the total risk of such stochastic effects resulting from the irradiation of the whole body

working level: the concentration of radon progeny in equilibrium with 3700 Bq/m^3 radon

working level month: special unit for inhalation exposure to radon progeny in air; it is equivalen to a 170 hour exposure to 1 "working level"

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